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SILICOSIS

IN THE METAL MINING INDUSTRY

A Revaluation • 1958-1961

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Silicosis in Metal Mining

View of Homestake Mining Co., Lead, S. Dak. *(Courtesy of Homestake Mining Co., 1963.)*

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SILICOSIS

IN THE METAL MINING INDUSTRY

A Revaluation • 1958–1961

U.S. DEPARTMENT OF HEALTH,
EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE

*Robert H. Flinn, M.D.; Hugh P. Brinton, Ph. D.; Henry N. Doyle,
Lewis J. Cralley, Ph. D.; Robert L. Harris, Jr.*

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

James Westfield; J. Howard Bird; Lawrence B. Berger

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Foreword

Throughout the history of mining, silicosis has been a major health problem. Efforts to control the disease did not begin in the United States until shortly after the turn of the 20th century, when the Public Health Service and the Bureau of Mines embarked on a series of joint investigations which contributed much basic knowledge on the etiology, pathology, and control of silicosis. However, it was not until about 1935 that the mining industries began major efforts to control the disease. Because of the long period involved in the development of silicosis, these efforts were not expected to lead to a demonstrable reduction in the prevalence of silicosis until many years later. In 1956, a study of compensation and other records pointed up the disease as a continuing problem of industrial, social, and economic significance. The present study was an outgrowth of hearings on mine health and safety held by the Committee on Education and Labor, House of Representatives, 84th Congress.

Because of the inadequacy of retrospective data on dust concentrations in the mines and silicosis prevalence rates due to the dearth of mine studies during the period 1940–61, it was not possible to answer all of the questions proposed in the objectives of the study. The study, however, should form the basis for others which could materially assist in ultimately eliminating silicosis as a serious threat to the health of metal miners.

Marling J. Ankeny. Harry Heimann

MARLING J. ANKENY
Director, Bureau of Mines
Department of the Interior

HARRY HEIMANN, M.D.
Chief, Division of Occupational Health
Bureau of State Services
Public Health Service
Department of Health, Education, and Welfare

Acknowledgments

Appreciation is expressed to the participating mining companies and labor unions for their excellent cooperation. Likewise, valuable assistance in organizing the study was given by the American Mining Congress and the various State mining associations. Without the assistance and cooperation of the State health departments and the State mining agencies it would have been impossible to carry out the study.

In addition, the success of a comprehensive study of this type depends upon the specialized skills of many individuals. The authors wish especially to acknowledge the following contributions in the environmental and medical aspects of the study.

Bureau of Mines—Members of the Health and Safety Activity of the Bureau of Mines performed as an effective team in both field and laboratory activities. Field studies were accomplished as scheduled, and laboratory production of analytical results kept pace with field operations.

Particular acknowledgment is made of the contributions to this report by Floyd G. Anderson, who participated in preparation of the section on History of Dust Sampling and Comparison of Methods; by Arthur L. Franks, Jr., Leslie Johnson, and Paul Schapiro, who analyzed field data and prepared material for the report; and by Joseph B. Stepan, who prepared the section entitled "Review of Environmental and Historical Records." Leslie Johnson was in charge of field operations, and Arthur L. Franks, Jr., and Paul P. Schapiro served as team leaders.

Others who took part in the field studies at various times were E. F. Allen, Walter Bank, R. C. Bates, C. J. Beecroft, R. L. Bernard, J. L. Brandt, W. B. Brogoitti, R. Capps, R. C. Derzay, A. M. Evans, R. L. Evans, G. B. Fritts, J. A. Fulmer, J. P. Harmon, T. Jolley, R. G. Peluso, H. G. Plimpton, E. J. Podgorski, H. E. Poland, R. O. Pynnonen, R. L. Rock, K. U. Russell, H. L. Schell, A. Schrader, D. K. Walker, M. L. Williams, and G. D. Winans.

Laboratory operations were conducted at Bureau of Mines stations at Pittsburgh, Pa., and Denver, Colo. At Pittsburgh, Floyd G. Anderson supervised particle-size determinations by optical microscopy, and

Peter J. Colbassani supervised X-ray diffraction and spectrographic determinations. At Denver, Russell Faddis and Harrison Hudson participated in operations pertaining to assessment of airborne dust, and Albert Maxian supervised analyses of all samples of mine air collected during the study.

Public Health Service—Staff members of the Division of Occupational Health located both at the Occupational Health Research and Training Facility at Cincinnati, Ohio, and at the Occupational Health Field Station, Salt Lake City, Utah, participated in the medical studies. Special appreciation is due to the following medical officers who conducted the examinations of miners: Mike Hayes, M.D.; Thomas H. Milby, M.D.; George H. Franck, M.D.; Raymond T. Moore, M.D.; Rodger K. Farr, M.D.; Robert Collier, M.D.; Nicholas P. Sinaly, M.D.; Patrick J. Hennelly, M.D.; Neely E. Pardee, M.D.; Willard P. Johnson, M.D.; and L. Bruce Bachman, M.D.; in addition, Victor E. Archer, M.D., conducted the medical examinations reported herein from the Uranium Miners' Survey of 1960.

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Much credit goes to Duncan Holaday for his assistance in getting the field work underway; to James Mueller and Frances E. Brogan for their help in the administrative phases of the study; and to Norma L. Egnew, Pius Zimmer, Helen McCool, and Mary Gabriel for their assistance with the statistical analyses. Miss Victoria Trasko has rendered valuable service in the final editing and collating of the manuscript.

The material presented as a retrospective study of a major silicosis control program was made possible by the enthusiastic cooperation extended by Dr. George W. Wright and Mr. Robert Downs of the Saranac Laboratory, and officials of the cooperating mining companies in the Lake Superior district, especially those of the Oglebay Norton Mining Co. and its Montreal mine, located at Montreal, Wis.

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CHAPTER I

Introduction

In 1956, the Committee on Education and Labor, House of Representatives, held a series of hearings on bills introduced in the 84th Congress relating to inspections and investigations in metallic and nonmetallic mines and quarries for the purpose of obtaining information relating to health, safety conditions, accidents, and occupational diseases therein. Testimony relating to the silicosis problem in the metal mining industry was presented at the December 1956 hearings by representatives of the Public Health Service and the Bureau of Mines. Although the committee did not recommend favorable action on the bills, as an outgrowth of the hearings, the Congress appropriated funds to the Public Health Service and the Bureau of Mines to revaluate the silicosis problem in the metal mines.

This report presents the major findings of the environmental and clinical studies conducted by the two agencies between March 1958 and September 1961 on the nature and scope of the silicosis problem in the metal mining industry. Also included is a retrospective study of a long-term silicosis control program and a discussion of the use of the International Radiological Classification of the Pneumoconioses in the study of silicosis.

BACKGROUND

The classic studies of the Public Health Service and the Bureau of Mines relating to dust diseases conducted between 1913 and 1940 made several important contributions to our knowledge of silicosis. They served to confirm the findings of many independent investigators and assisted in determining the etiology and pathology of the disease. The studies helped immeasurably in the assay of dust exposure and in defining the role of such factors as particle size, composition of the dust, and duration of exposure, and led ultimately to the adoption of 5 million particles per cubic foot of air as a maxi-

mal allowable concentration of silica dust.[1]* The year 1935, or thereabouts, saw recognition and acceptance of the five cardinal factors in the etiology of silicosis: composition of the dust, concentration of the dust, size of the dust particles, duration of exposure, and individual susceptibility.

On April 14, 1936, the Secretary of Labor, recognizing the confusion which existed at the time regarding silicosis, called the First National Silicosis Conference.[2] After a general discussion, the conference agreed to organize four committees to do at least three things: (1) study specific phases of the silicosis problem; (2) assemble in a series of reports the essential facts about silicosis; and (3) present specific suggestions for silicosis prevention and for straightening out other difficulties that silicosis had created. The reports of the committees served to clarify many aspects of the problem by defining the etiology of the disease, its relationship to tuberculosis, and the medical and engineering control methods. The conference was doubtlessly a motivating factor for furthering silicosis control in the mining industry as well as other dusty trades.

Because of the need to concentrate on other problems, the late 1930's saw a diminishing emphasis by the Public Health Service and the Bureau of Mines on the epidemiology of dust diseases. This decision was undoubtedly influenced by the onset of World War II and its attendant problems. The middle 1930's also marked the introduction of extensive dust control programs by the larger metal mining companies. To what extent the World War II period, when dust control activities were doubtlessly slackened because of equipment shortages and production demands, might have affected progress had to be considered.

In the middle 1950's, the Public Health Service began to consider revaluation of the silicosis problem. The precipitating factor was an invitation to the Division of Occupational Health, Public Health Service, to present a paper on "The Accomplishments in the Epidemiologic Study of Silicosis in the United States" [3] at the 1955 McIntyre Saranac Symposium on Silicosis. To prepare the paper, a brief study of the prevalence of silicosis was conducted. Three general conclusions were drawn from this preliminary review: (1) silicosis remained the major occupational disease in the United States; (2) tuberculosis was not so prevalent as it once was among silicotics; and (3) because of present day compensation laws and enlightened employment practices, the disease no longer has extreme and unique social consequences.

However, the uncovering of a relatively large number of cases of silicosis raised some rather significant questions. These in-

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*Numbers refer to reference list at the end of the chapter.

cluded: (1) Do the initial exposures in the presently occurring cases date back to precontrol days? If so, do those cases represent progression of the disease due to continued exposure to low concentrations of silica dust? (2) How extensive and efficient is dust control in relation to recommended standards? (3) Do our standards need revision? (4) Are there other factors to which proper attention is not given, such as particle size? (5) What is the actual toxicity of silica? In addition, the need was pointed up to devise a practical means of assessing disability, as well as to develop a satisfactory X-ray classification system.

Following the McIntyre Saranac Symposium, which pointed to a serious need for current knowledge on the scope of the silicosis problem in the United States, two additional steps were taken. The first was to conduct a more extensive study of the prevalence of silicosis. By 1956, a review of compensation and other records of official agencies covering the period 1950–54 had been completed which showed that 10,362 cases of silicosis had been compensated or reported in one form or another in 22 States.[4] This sizable silicotic population was primarily an elderly group, with over 75 percent of the cases 50 years and older. Of 3,455 persons for whom reasonably adequate employment histories were obtained, only 10 percent allegedly received their entire dust exposure after 1935. The total mining industry contributed two-thirds of all the cases; metal mining accounted for 24.5 percent of all the cases in the mining industry. In the manufacturing group, which accounted for 27.6 percent, the foundry industry was the largest contributor.

The second step was to revaluate the silicosis problem in the granite-cutting industry. This industry had been the subject of a detailed study by the Public Health Service in the middle 1920's and again in the later 1930's.[5 6] The most striking finding of these early studies was the almost universal occurrence of silicosis among the workers exposed over 10 years to dust concentrations above 40 million particles per cubic foot of air with a 35-percent free silica content.

The revaluation of the granite industry in 1956 revealed that the dust concentrations at that time were well below the recommended State standard of 10 million particles per cubic foot for granite dust. Insofar as records indicated, and within the limitations of the X-ray equipment available, not a single case of silicosis had developed in a granite-shed worker whose initial exposure followed the installation of dust controls.[7] One cannot assume that the dust concentrations found in the 1956 survey were representative of those to which workers were exposed over the previous 20 years; indeed, there is evidence that dust control measures in the granite sheds, as in many other dusty industries, had deteriorated during the 8- to 10-year period influenced by World War II. The study did indicate, how-

ever, that with adequate environmental controls, silicosis might be prevented or its development delayed considerably beyond the 20-year exposure period.

A third unexpected opportunity for further study presented itself in December 1956 when the Committee on Education and Labor, House of Representatives, held its major hearing on bills introduced in the 84th Congress relating to inspections and investigations in metallic and nonmetallic mines and quarries.[8] A substantial part of the hearing was devoted to the silicosis problem and testimony was presented by the Public Health Service and the Bureau of Mines. As an outgrowth of the hearing, the Congress appropriated funds to the Public Health Service and the Bureau of Mines to revaluate the silicosis problem in the metal mining industry.

METHODOLOGY

Following the appropriation of funds by the Congress, an Interagency Technical Committee composed of three representatives and an alternate each from the Bureau of Mines and the Public Health Service was appointed in September 1958 to organize and direct a joint study of silicosis in the metal mining industry. A major responsibility of the Committee was to determine objectives, policies, and procedures to be used in the study. The objective of the study was defined as the determination of the prevalence of silicosis and assessment of the present day environmental conditions in the metal mining industry. The study was designed to answer three important questions. These were: (1) Are the cases presently occurring the result of pre-control exposure, in view of the long latent period for the development of silicosis? (2) Are they accounted for by the failure to apply controls universally? (3) Are the silicosis cases occurring because of the inadequacy of standards in use since 1935?

The study was limited to active, underground metal mines employing more than 20 persons underground, but it was broad enough to include all major commodities in the various mining areas of the United States. The medical examinations consisted of a 14- by 17-inch chest roentgenogram, an occupational and medical history, and simple pulmonary function tests of employees of mines included in the study.

Through engineering studies, environmental conditions were evaluated by determining dust concentrations and existing dust control measures. Dust evaluations included the determination of the concentration, particle size, and composition of the dust. Airborne dust and dust-source material were analyzed by X-ray diffraction

for free silica and by spectrographic methods for chemical composition. Ventilation rates were measured. Weighted dust exposures were determined for each major underground occupation. Mine air samples were collected in sufficient numbers to permit the evaluation of exposures to carbon monoxide, carbon dioxide, and oxides of nitrogen.

Because previous studies had utilized the impinger and the reference standard was based on this instrument, the Committee agreed that it would be the basic sampling instrument in the environmental study. However, it was felt that it would be well to supplement the impinger with the thermal precipitator, the electrostatic precipitator, and a filter paper sampler. For various technical reasons, the thermal precipitator was used for only a portion of the routine study and use of the electrostatic precipitator was limited largely to a special supplemental investigation. The filter paper technique was continued throughout the study, but the sample was only used for particle sizing. For particle-size determination, both the optical and the electron microscope were used.

The Committee, recognizing the importance of exploring various dust quantitation techniques other than the impinger method, agreed that special dust sampling studies would be conducted in laboratories of the Public Health Service and the Bureau of Mines, and in selected mines. These studies were performed to compare the results yielded by a variety of dust sampling and quantitation techniques with those obtained by the standard impinger method as used in the routine surveys.

Very early in its deliberations, the Committee concluded that the success of the study would depend upon keeping and presenting the data in such a manner that the identity of the mines and individuals would not be disclosed. Such procedures are also in accordance with the policies of the Department of the Interior and the Department of Health, Education, and Welfare. It was, therefore, decided that neither engineering nor medical data as they related to an individual or a mining company would be revealed to State officials, management, labor, or others outside the Public Health Service or Bureau of Mines. However, following each mine survey, the Bureau of Mines conferred with mine management to report general findings. The companies were also advised by letter of the free silica content of settled dust samples from its mine and the spectrographic analysis of a composited ore sample.

For medical data, an exception was to be made only when the X-ray film revealed a condition that needed immediate medical attention, such as suspected cancer, tuberculosis, or heart disease. In such cases, the employee's personal physician was notified by the Public Health Service, if so authorized by the employee.

To assure high diagnostic standards, the roentgenographic films were first screened for quality and unusual pathology by physicians of the Division of Occupational Health, Public Health Service, and then read by a panel of outstanding radiologists in accordance with the International Classification of Radiographs of the Pneumoconioses (International Labour Office, Geneva, 1958).

A major task of the Interagency Technical Committee was to inform industry, labor unions, and official agencies of the study plans. To assure acceptance at the national level, meetings were held with officials and representatives of the American Mining Congress and the major national labor unions involved. The labor unions readily agreed to the limitations which were placed on the dissemination of information. Through their communication channels, the national labor unions advised their locals of the proposed investigation.

Following these discussions, most of the States in which the studies were to be conducted were visited to discuss the proposal with safety and health officials as well as representatives of the State mining associations. Most of the State mining associations contacted indicated willingness to cooperate. Individual contacts were then made with mining companies by a representative of either the Public Health Service or the Bureau of Mines, and in many cases, by a joint approach.

The cooperation of the operating companies was generally quite good, although it varied to some extent among the various mining districts. For instance, in the Western States, no company declined to participate in the study. In other parts of the country, a few companies would permit only the environmental investigation, being apprehensive that the medical study might cause some concern among their employees and reopen the question of compensation. However, since the environmental data would be of limited value unless accompanied by the corresponding medical information, these mines were eliminated from the sample. A small group of mines objected to the conduct of either the medical or the environmental examinations. Figure I.1 shows the States in which the survey was conducted.

As an outgrowth of the study, a group of mines in the Lake Superior district volunteered to make available to the Public Health Service and the Bureau of Mines the medical and engineering data obtained in their silicosis control program, which began in 1933. Through the Saranac Laboratory, which conducted the medical program, serial films on about 5,000 miners were available for study, some covering a period of almost 30 years. These data permitted a detailed analysis of present day and past conditions and were invaluable in relating the development and progression of silicosis to a dust control program.

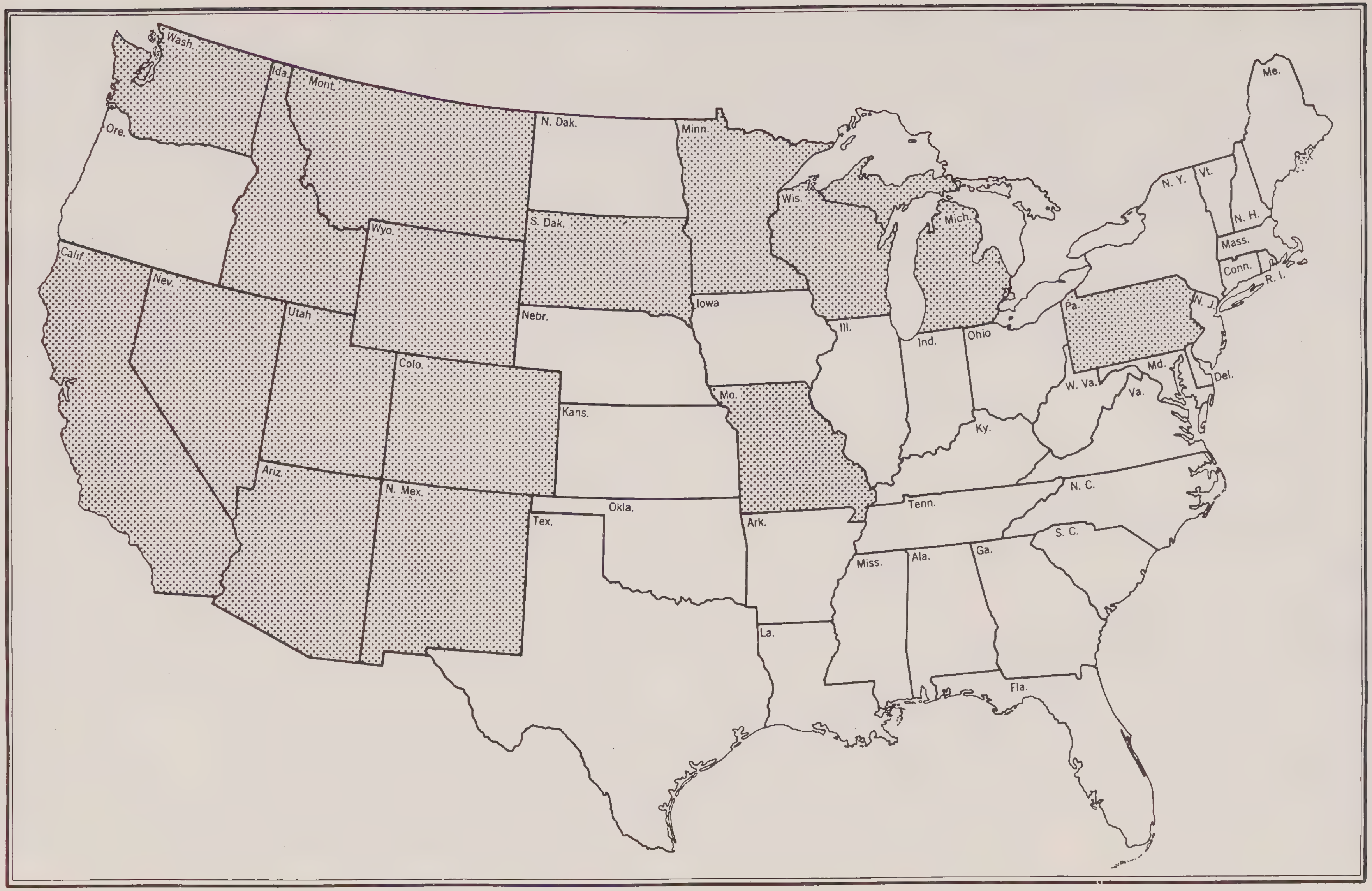

FIGURE I.1.—States in which mine studies were made.

Other companies volunteered their mines for more detailed environmental studies on particle size, effectiveness of various engineering control methods, the relationship of airborne silica to the silica content of the settled dust, and medical data which were needed to supplement the present study.

The 67 underground mines in the environmental study included 14 iron mines with 4,231 employees, 11 copper mines with 7,260 employees, 22 lead-zinc-silver mines with 4,281 employees, a miscellaneous group of 12 mines with 4,365 employees, and 8 uranium mines with 373 employees. Since it was necessary to limit the magnitude of the study, open pit mines were not included.

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Richest Hill on Earth. Butte, Mont. Plumes are from surface fans.
(Courtesy of The Anaconda Co., 1963.)

CHAPTER II

Summary, Conclusions, and Recommendations

SUMMARY

A revaluation of the prevalence of silicosis in the metal mining industry of the United States was carried out by the Division of Occupational Health, Public Health Service, Department of Health, Education, and Welfare, and the Bureau of Mines, Department of the Interior, between March 1958 and September 1961. The study was an outgrowth of hearings before the Committee on Education and Labor, House of Representatives, 84th Congress, Washington, D.C., December 1956.

At the turn of the century there was a growing awareness of the problem of silicosis and frequently associated tuberculosis among workers in the dusty trades in this country. During subsequent years a series of studies was initiated to define the problem and institute control programs. Included in this series was a number of studies of silicosis in the metal mines. These metal mine studies showed that massive dust exposures often were encountered and that scarcely any of the employees were free of harmful dust exposure. When the dust had a high free silica content, employees exposed to massive levels developed severe silicosis within a few years. It was common to find silicosis in 30 to 80 percent of the employees of specific mines studied. In these early studies, up to 60 percent of the employees with silicosis also had tuberculosis.

In the mid-1930's a large part of the metal mining industry instituted major dust control practices. World War II, however, imposed major difficulties in the followup and development of these practices. The war also curtailed the attention given to research and studies on silicosis in metal mines. This and other postwar problems resulted in a dearth of information on the subject.

In 1954 the Public Health Service began a revaluation of silicosis as an occupational disease problem. This consisted first of a study of compensation and other records of official agencies to determine the magnitude of the silicosis problem. During a 5-year period, 1950–54, 10,362 cases of silicosis had been compensated or

reported in 22 States from all industries. The silicotic population was primarily an older group with 75 percent of the cases being 50 years and older. Of 3,455 persons for whom reasonably adequate employment histories were available, only 10 percent allegedly received their entire dust exposure after 1935. The total mining industry contributed two-thirds of all the cases; metal mining accounted for 24.5 percent of these cases. A revaluation of the granite cutting industry in Vermont in 1956 revealed that the dust concentrations at the time of the survey were well below 5 million particles per cubic foot of air, and that records revealed no cases of silicosis among the granite workers whose initial exposure followed the installation of dust controls in the mid-1930's.

Consequently, at the start of this study (1958–61), it was not known whether the present prevalence of silicosis in the metal mines resulted from a reservoir of miners still working who had significant exposures before dust control practices were instituted, or was due to the lack of application of dust control practices or to inadequate standards.

The medical phase of the study was conducted by the Division of Occupational Health of the Public Health Service and the environmental phase by the Bureau of Mines. The environmental study included 67 underground mines employing approximately 20,500 persons—14,000 of whom worked underground and 6,500 in surface occupations. At the time of the study this group represented more than 50 percent of the working population of underground metal mines in the United States. The medical study included employees from 50 of the above 67 metal mines and a large number of uranium mines. The mines included in the study represented virtually all metals mined in commercially significant quantities in the United States and represented all principal mining methods. Only underground mines employing 20 or more men were studied. The study was the most extensive thus far undertaken in the metal mining industry of the United States.

Environmental Study

In the environmental study particular emphasis was placed on evaluation of airborne dust in mine working areas. Observations were made also of pertinent factors such as dust control methods, ventilation, methods of working, and air quality.

Mine dust must have three characteristics to be capable of producing silicosis: (1) it must contain crystalline silicon dioxide, such as quartz, (2) it must be in the respirable particle-size range, and

(3) it must be present in sufficient concentration. Thus, in a mine program for prevention of silicosis, the variable which lends itself to control is (3)—the concentration of dust.

Determination of the alpha-quartz content of the host rock in the various mining areas studied indicated a range from less than 1 percent to 95 percent. Dust exposures were evaluated for the mines studied on the basis of the quartz content of 234 samples of settled dust collected from mine working areas. Quartz in the settled dust ranged from less than 2 percent to 95 percent. In 55 percent of the mines the settled dust contained less than 20 percent quartz; 39 percent of the mines were in the range of 20–50 percent quartz; and 6 percent of the mines were above 50 percent quartz.

Particle-size characteristics of 481 samples of airborne dust were determined by optical microscopy, using the oil immersion technique. Median particle diameter was 0.36 micron. Comparison of particle-size characteristics on split samples using both optical and electron microscopy indicated that there was not a preponderance of submicron particles below the range detectable by optical microscopy using the oil immersion technique. Little difference was found in size properties of airborne dust produced in the various mining operations. All determinations indicated ranges of size of particles capable of significant retention in the alveolar spaces of the lungs.

The impinger was used as the principal instrument for sampling airborne dust throughout the environmental study. The threshold limit value for industrial dust currently recognized in the United States is based upon determination of airborne dust by use of this instrument. Furthermore, the impinger has been employed as the dust-assessing instrument in previous studies, dating back more than 25 years, in which the health status of workers has been correlated with their occupational exposure to dust. Thus, its use in this study permitted comparison of overall findings with results of previous studies.

In discussing results of the study, the threshold limit value for siliceous dust adopted by the American Conference of Governmental Industrial Hygienists as acceptable for occupational exposure was used as a guideline for evaluating the concentrations of airborne dust as determined in the study. The threshold limit values in effect during the period of the study, 1958–61, had been recognized since the mid-1940's. In 1962, however, the American Conference of Governmental Industrial Hygienists (ACGIH) adopted a new threshold limit value for dusts containing silica. Results of the study were considered in respect to both sets of threshold limit values. Neither of these sets of values were used, however, as sharp lines of distinction between safe and unsafe conditions, but merely as base lines or reference points for comparison of observed conditions.

The threshold limit value is applicable to the interpretation of daylong integrated, or "weighted average," exposures. Although the threshold limit value is not applicable to single samples, it is convenient to have some means for their classification. Individual samples of airborne dust that could contribute significantly to weighted average exposures that would exceed 1962 ACGIH threshold limit values are considered as containing "excessive dust." It is emphasized that the working environment as assessed, represented conditions existing only at the time of the sampling; the results may not be interpreted as representative of past or future conditions.

A total of 14,480 impinger samples was collected in underground working places. Of the samples, 75.6 percent were in the range of 0–5 million particles per cubic foot of air (mppcf); 19.3 percent in the 5–20 mppcf range; 3.9 percent in the 20–50 mppcf range; and 1.2 percent over 50 mppcf. An additional 357 samples were collected in intake and return airways not considered as occupied working places. Of the grand total 14,837 impinger samples collected underground, 1,440, or 9.7 percent, contained excessive concentrations of dust.

During the study 789 full-shift weighted average exposures were determined to provide an evaluation of specific underground operations. These determinations applied only to operations, as such, and were not intended to classify the total underground mining population into various degrees of dust exposure. Based upon the threshold limit value that was in effect during the study, 44, or 5.6 percent, of the weighted average exposures exceeded the limit; whereas, on the basis of the 1962 threshold limit value, 104, or 13.2 percent of the weighted averages, were above the threshold limit value. Distribution of weighted averages that exceeded the threshold limit value was not uniform among the 67 mines studied.

In relation to the threshold limit value in effect between 1958–61, none of the weighted averages determined in 46 mines exceeded the limit. In relation to the 1962 threshold limit value, 30 mines had no weighted averages above the limit. Among the other mines the number of weighted averages above the threshold limit value varied from one per mine to five or more per mine. It was notable that a few mines contributed a major portion of the weighted average exposures that exceeded the limit, indicating need for more overall attention to the dust control programs at these mines. It is emphasized also that in every mine studied some individual impinger samples contained excessive dust, indicating need for improved dust control at these particular locations.

A comparison of dust concentrations obtained at a group of lead-zinc mines in the Western States with dust concentrations obtained

in Utah lead-zinc mines in 1939, indicated very substantial improvement in dust control during the years intervening between the studies. Dust concentrations for comparable occupations underground had been reduced at least 80 percent, and in some instances as much as 90 percent. Dust concentrations for comparable occupations on the surface had been reduced a minimum of 50 percent, and in some cases as much as 90 percent.

Medical Study

Medical examinations, including medical histories and symptoms, occupational histories and chest roentgenograms were completed on a total of 14,076 currently employed metal mine workers. Two simple pulmonary function tests were performed by each participant unless maximal respiratory exertion was thought by the team physician to be contraindicated.

Participation in the survey was on a voluntary basis, but every effort was made by the Public Health Service working with company and union officials to examine all mine employees. The response varied widely from 50 percent to 100 percent, the overall average being 77 percent for the 50 nonuranium mines included in the study. In nine mines 90 percent or more of the employees participated and, of these, three small mines had 100-percent participation.

Of the 14,076 chest roentgenograms taken, 476 or 3.4 percent were classified as consistent with a diagnosis of silicosis. Of these, 305 were classified as simple silicosis and 171 were classified as complicated silicosis. Although the overall prevalence rate for the study was 3.4 percent, the prevalence varied greatly, ranging from 12.9 percent in one mine to zero in seven mines. Thirteen mines had a prevalence rate of less than 1 precent silicosis while five mines had more than 7 percent.

This overall silicosis prevalence rate of 3.4 percent was in marked contrast with rates revealed by earlier studies of silicosis among metal mine workers conducted in various areas of the country between the years of 1914 and 1935. In some of these early studies more than 60 percent of the workers were found to have roentgenologic evidence of silicosis, and the prevalence rate seldom was less than 25 percent.

Silicosis in the 1958–61 study, for the most part, was confined to the older miners with more than 15 years of metal mining experience. Silicosis was not observed in the chest film of any miner under 35 years of age, and only seven cases, or 0.4 percent, were found in the 35–39-year age group. Beginning with the 40–44-year

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age group with a prevalence rate of 2.4 percent, there was a moderate increase in the rate with each succeeding age group until it tended to level off at about 12 percent for men from 55 to 64 years of age. Of 63 men examined who were 65 years or older, about one-third were silicotic.

In relating silicosis to years of work at the mines, no cases occurred with less than 5 years of exposure. Seven cases, or 0.2 percent, occurred in workers with 5–9 years of exposure. Thirty-five cases, or 1.4 percent, occurred with 10–14 years of exposure and 58 cases, or 3.0 percent, occurred with 15–19 years of exposure. After 20 years of exposure the prevalence rates rose rapidly in 5-year increments from 7.6 and 12.1 percent up to an average rate of about 17 percent for the four exposure groups working 30, 35, 40 and 45 years and over.

A past history of pulmonary tuberculosis was reported quite infrequently by this employed mining population, being well under 1 percent in the large nonsilicotic population and reaching only 3.8 percent in the silicotic groupings. An evaluation of the case histories and a recheck of the related X-ray film interpretations, moreover, showed that some of these histories could not be proven, as relatively few showed definite evidence of past pulmonary infection. On the other hand, actual X-ray evidence of past tuberculous infection as shown by review of all the chest films was found in 0.6 percent of the total nonsilicotic and 5.3 percent of the silicotic population, a low rate as compared with earlier studies of silicosis and tuberculosis.

Information on other illnesses was solicited in the medical history which was obtained from each worker examined. A history of pneumonia was reported by about one-fifth to one-fourth of all employees, increasing slightly with age. Pleurisy was reported somewhat less frequently than pneumonia, especially among the nonsilicotic employees. Bronchitis was reported in a small percentage of all employees, increasing very slightly with age and showed only a small increase in prevalence among the silicotic workers. Asthma was reported in about 4 to 6 percent of all employees in both the silicotic and nonsilicotic groups.

Shortness of breath was reported by less than 5 percent of the nonsilicotic miners under 35 years of age, but gradually increased to 18.4 percent among miners 55 years of age and over; for the same age groups, shortness of breath was reported twice as often in the silicotic population. It was more prevalent among persons with complicated than those with simple silicosis. There were only slight differences in the prevalence of shortness of breath at the various elevations of the mines.

A history of lead poisoning and mercurial poisoning was reported very infrequently as compared with previous studies. If only men working at mines producing lead in the present study are considered, there were 26 workers or 0.7 percent who reported lead poisoning at any time in the past. In the entire study 23 cases of mercurial poisoning were reported by the miners interviewed. Among 309 employees at mercury mines, 7 said they had been affected at some time with mercurial poisoning.

So far as possible, each employee was classified according to his principal occupation. This generally was the broad occupational group in which he had spent more than half of his working life in the metal mining industry, regardless of his present occupation which might have changed in recent years.* All men, however, who had spent 10 years or more at the working face of the mines were classified as "faceworkers."

Over one-half of all silicosis cases occurred among men who were classified as faceworkers. With 10–19 years of mining employment they showed a silicosis prevalence of 3 percent which rose to 19 percent among men working 20 years or longer. Smaller, but significant silicosis rates were also found among employees with more than 20 years of employment in other underground operations, surface maintenance and construction work, and surface mill operations. Surface transportation and miscellaneous surface operations showed very few cases of silicosis. Silicosis was often found at the time of the survey among older surface workers who had previously spent many years underground, but had been transferred to surface operations for various reasons.

The mines were divided according to the size of their working population and the prevalence of silicosis in each mine was expressed as the percentage of employees so affected. There was little relationship between the size of the mines and the prevalence of silicosis. Attention was also directed toward the question as to whether the silicosis found at a metal mine was attributable solely to employment at that mine or to a combination of work experience at several mines. A comparison of silicosis rates for groups of employees who had experience in one mine only, and for groups of employees with experience in two or more mines, showed little difference when similar occupations and periods of exposure were compared. The prevalence of silicosis was slightly greater among employees with experience in two or more mines.

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*This tabulation does not include uranium miners, many of whom could not be classified by principal occupation, and workers at seven iron and lead-zinc mines situated in low free silica limestone formation, who were found to have a negligible prevalence of silicosis in all occupations.

The prevalence of silicosis among workers in mines producing iron, lead-zinc, copper, uranium, and miscellaneous commodities was determined by each commodity. There was no great difference in the pattern of silicosis prevalence which could be attributed to the difference in commodities.

Men having had 5 or more years of exposure in other dusty trades in addition to the metal mining industry, were excluded from the study group because of the possibility that the prevalence of silicosis in such a mixed exposure group would be unduly influenced by other dusty employment. Among this mixed exposure group it was noted that, when the total duration of employment in dusty trades was approximately the same, the silicosis prevalence rates were very similar to that of metal mine workers included in the study. It thus appears that the exclusion of 671 workers from the study group because of previous exposure in other dusty trades did not appreciably alter the results of the study.

In general, great advances have been made by the metal mining industry in controlling the silicosis hazard, beginning about the mid-1930's. The effects of these dust control measures would not have been evident until many years later, because of the reservoir of miners exposed to dust prior to this period.

Fortunately the 1939 Study of Non-Ferrous Metal Mine Workers in Utah presented data which may be contrasted with data from a group of 12 western lead-zinc mines investigated during the present survey (1958–61). The overall prevalence of silicosis was found to be 40 percent lower than in the earlier study. Even more striking was the reduction of 80 percent in the silicosis rate among persons employed in the mines less than 10 years and 73 percent for the group employed 10–19 years. The environmental data of the 1958–61 survey also showed a very favorable trend in reduction from the atmospheric dust levels found in the 1939 Utah survey.

An analysis was also made of comparative prevalence rates within the 1958–61 study for silicosis among metal mine workers who had worked in the industry only since 1935 or later, and those who had some portion of their employment before 1935 as well as later, excluding those at seven mines located in low free silica limestone formations. This permits some comparison of silicosis prevalence rates among workers within this study who had substantial exposure before dust control measures became widely used, and those employed only during the subsequent 25 years or so. Among the relatively small group of miners with some mining experience before 1935, but who had worked in metal mines a total of only 10–14 years, the silicosis rate was 6.1 percent; a group of 1,818 miners who had worked the same number of years but only in 1935 or later had

a rate of 1.5 percent. Figures for persons with 15–19 years in metal mines showed 8.3 percent with silicosis in the pre-1935 group and 3.3 percent with silicosis in the after-1935 group. After 20–24 years in metal mining, men with experience prior to 1935 had a silicosis prevalence of 12.7 percent compared with 7.2 percent for miners with experience during or after 1935. This is a trend similar to that shown in comparing the present study with the 1939 Utah study.

A special study was made of the records of a group of metal mine workers from one iron mine which had a continuous silicosis control program underway since 1933. Beginning with the records of that year it was possible to examine X-ray films of all workers then employed and others as they were hired and to follow the entire group year by year as serial X-ray films were taken throughout the 28-year period. Complete work records were also available for analysis.

Among the 1,293 men included in this study, 410 had worked before 1933, and thus had been exposed before the improvement in the mine environment. Silicosis was found at the time of first X-ray examinations in 1933 in 83 men, and 16 men who were negative in 1933 developed silicosis later. Among the 883 men who were first employed after the control program began in 1933, there was not a single case of silicosis which developed even in a substantial group with more than 20 years of exposure. Only 6 percent of the men with silicosis showed any progressive change in the disease as they continued mining employment.

CONCLUSIONS

Prior to the beginning of this study it was known that in recent years substantial numbers of men who had been employed in the metal mining industry were awarded disability compensation for silicosis. With silicosis thus known to occur in the industry the study was designed to determine the prevalence of silicosis among the work force of the industry, to define present day environmental conditions, and to seek answers to the questions:

1. Are the cases presently occurring the result of pre-control exposure, in view of the long latent period for the development of silicosis?
2. Are they the result of failure to apply dust controls universally?
3. Are cases occurring because of inadequacy of standards for acceptable levels of dustiness in use since 1935?

Findings of the study lead to the following conclusions with regard to these questions and to other facets of the problem:

1. Considerable progress has been made in the metal mining industry in the prevention of silicosis. The present overall prevalence rate of 3.4 percent is substantially lower than the rates encountered in previous surveys. The range varied among individual mines, however, from 0 to 12.9 percent and shows the prevalence of silicosis is not uniformly distributed throughout the industry.
2. The industry has instituted or improved many dust monitoring and dust control systems during the past 25 years; this has resulted in marked reductions in dust exposures. Since the development of silicosis requires a considerable period of exposure, the full benefits of these improved environmental working conditions cannot be fully evaluated at this time.
3. There was a substantially higher prevalence of silicosis among men who worked in mining at some time before 1935 as compared with men who have worked the same number of years only since 1935. Two hundred and ninety-eight cases of silicosis were found in workers whose work history began prior to 1935.
4. One hundred and twenty-eight cases of silicosis were found among men exposed only since 1935. This finding, together with excessive dust exposures in some of the mines studied, provides evidence that effective dust control has not been universally practiced.
5. Data obtained in the study do not permit judgment of the adequacy of present standards. In most of the mines studied, environmental data to define working conditions from 1935 to the time of this study were lacking.
6. Combined medical and environmental surveillance and control can prevent the development of clinically significant silicosis among miners.
7. With regard to specific environmental situations the following can be concluded:
    a. In many instances, ventilating currents in the working areas were not being used to best advantage. Recirculation of air particularly posed a problem in that airborne dust was often carried from one working place to another.
    b. Drilling, slushing, and mucking were the most prolific dust-producing operations to which men at the face were exposed. Workmen engaged in haulage and

crusher operations were also exposed, in several instances, to excessive concentrations of dust.

c. Water applied to the muck piles assisted materially in reducing dust concentrations during subsequent operations.

d. Dust concentrations in shops and mills, except during cleanup operations, presented no particular problems.

e. The need for better maintenance and cleanup practices around crusher installations was indicated.

f. Concentrate loading and cement mixing were sources of excessive concentrations of dust; however, very few workmen were engaged in such operations.

8. This study has provided extensive and basic data on the current prevalence and characteristics of silicosis among employed metal miners and on the magnitude and nature of current dust exposures in the metal mining industry. It represents an important baseline for continued studies. In view of the long latent period for the development of silicosis, further comprehensive medical and environmental studies over a period of years will be necessary to develop additional essential information on the problem. This will include determining if new cases of silicosis are occurring or known cases are progressing, their relationship to occupational dust exposures, the need for improved or additional dust control measures and the adequacy of present standards for evaluating siliceous dust exposures.

RECOMMENDATIONS

The following recommendations are generally applicable to the Nation's underground metal mining industry. It was unusual to find all recommendations being practiced by any company, although many were being followed by some of the participating companies at the time of the study.

General

Periodic medical and environmental studies should be continued by the Public Health Service and the Bureau of Mines at approximately 5-year intervals. These should be continued for a sufficient period of time to determine the incidence and trend of silicosis in the industry and to determine the adequacy of standards for safe dust exposure. Also, research on dust sampling, analytical methods, and dust control methods should be continued and expanded.

1. Each mining company should maintain a dust monitoring program conducted or supervised by a person competent in the techniques of dust sampling and interpretation of results.
   a. For determining levels of exposure, dust samples should be taken in the breathing zones of workmen.
   b. The program should be conducted in such a manner that it will detect changes in environmental conditions and promptly locate conditions in need of correction.
   c. Accurate and complete records of dust conditions should be kept. These should be tabulated, analyzed, and reported to a responsible level of management at regular intervals.
2. Proper methods of dust control should be initiated promptly when the need is discovered.
   a. Adequate ventilation by mechanical means should be provided at all working places.
   b. Recirculation of air should be held to a minimum consistent with good mining practice.
   c. All ore and broken rock should be thoroughly wetted to reduce dust during subsequent handling operations.
   d. All dust control devices and materials handling equipment, both underground and on surface, should be frequently inspected and maintained in proper working condition to limit to the lowest practicable level the generation or dispersion of dust.
   e. Men should not be permitted to reenter a workplace after blasting until sufficient time has elapsed for dust and gases to be reduced to a safe level.
3. Workers should be informed of the dust hazards associated with their job, the methods employed for the control of dust exposure, and instructed in good work procedures to minimize dust dispersion and in the proper use of equipment. All employees should give their full cooperation in helping to maintain an effective dust control program.
4. Mining companies should request, whenever necessary, the assistance of the Bureau of Mines or other qualified agencies in instituting and evaluating dust monitoring and dust control programs.

1. Medical examinations
    a. All men entering the metal mining industry should have a preplacement physical examination including a technically satisfactory X-ray film of the chest.
    b. Periodic physical examinations including an X-ray chest film should be performed annually on underground workers, and biennially on surface workers in order to detect early silicotic changes, evidence of active pulmonary tuberculosis, or other pulmonary disorders.
    c. No worker should be denied employment for which he is trained because of simple silicosis but rather he should be permitted to work in an environment with effective dust control that would be safe both for him and his fellow workers.
    d. Any employee found to have active pulmonary tuberculosis should be placed under treatment and should not be permitted to resume employment at a dusty occupation. Workers with minimal, arrested, or healed reinfection tuberculosis should be allowed to continue to work, but should observe the same precautions as the man with simple silicosis. Healed primary tuberculosis does not seem to be a contraindication for employment in a dusty trade.
2. Health supervision and practices: Although the following recommendations were not developed directly as a result of the 1958–61 silicosis study, they represent standards of good practice and for the most part result from previous studies of the Public Health Service and the Bureau of Mines.
    a. Close medical supervision is desirable for all employees in order to prevent or control ordinary respiratory infections, and other common illnesses. During the course of medical examinations and day-to-day visits to the hospital or clinic, employees should be advised on various aspects of hygiene and preventive medicine.
    b. Employees returning to work after an absence due to an injury or illness should be cleared through the medical service to insure their being physically fit for their jobs, thereby protecting their own and their coworkers' health and safety.

c. The mine physician, whether full or part time, should be familiar with the various mining operations and their potential health hazards and should make periodic sanitary inspections. The official health department should be informed of any conditions requiring technical or specialized assistance. Also, the physician should be in close communication with plant safety and dust control personnel.

d. All mines should provide conveniently located change houses with facilities for hot and cold shower baths, and lockers and drying rooms for work and street clothing.

e. Records of all absenteeism due to illness or injury should be kept by the mine medical department indicating the course, nature, duration, and outcome of such disability. These records should be tabulated and analyzed in a monthly report to serve as a basis for study and corrective measures to promote employee health and minimize such absenteeism.

Bishop Mine—Union Carbide Nuclear Co., Bishop, Calif. (Courtesy of Union Carbide Nuclear Co., 1963.)

CHAPTER III

Review of Past Studies

A review of past studies reveals the scope and severity of the silicosis problem in the metal mines of this country during the first four decades of this century and of the efforts through environmental and medical measures to control the problem. A general awareness of the severity of silicosis and tuberculosis among workers in the dusty trades became apparent at the turn of the century. The equally apparent high prevalence of "miner's consumption" and tuberculosis among metal miners drew attention to the need for studies in the mines and the institution of control measures.

The first major investigation of silicosis in the metal mines in the United States was made in the Joplin, Mo., mining district in 1914–15 through a cooperative study by the Bureau of Mines and the Public Health Service.[1] * Of a total of 93 miners examined, 64, or 68.8 percent showed definite evidence of pulmonary disease. Of these 64 miners, 39 had the classical symptoms of pulmonary tuberculosis. Environmental studies showed that the miners were exposed to massive dust concentrations arising from such operations as blowing of dry holes, squibbing, boulder popping, dry drilling, and dry handling of the ore. Atmospheric dust concentrations as high as 6 to 7 milligrams per 100 liters of air were common.

To further define the silicosis problem among miners in this district, a more comprehensive study was made in 1915.[2] Of 720 miners examined, 472 or 65.5 percent had silicosis. Of the 472 miners with silicosis, 21.8 percent also had pulmonary tuberculosis. The environmental study bore out the extreme dustiness of the various operations found during the previous study and further revealed that the chert in the mines contained free silica ranging from 70 to over 95 percent.

During 1916–19, the Bureau of Mines and the Public Health Service conducted a cooperative study of the prevalence and cause of miner's consumption in the Butte, Mont., district.[3] Of 1,018 miners examined, 432 or 42.4 percent showed definite signs of dust injury to the lungs. Of the 432 miners with silicosis, 14.6 percent also had pulmonary tuberculosis. The environmental data revealed that

*Numbers refer to the reference list at the end of the chapter.

the Butte mines in general were more dusty than the Joplin district mines but that, in contrast, the dust of the Butte mines contained only 50 to 60 percent free silica compared to the over 90 percent free silica of the dust in the Joplin mines.

An examination of 303 gold miners in Nevada in 1921 [4] showed that 80 percent had silicosis. During the same year an examination of 181 gold miners in California showed that 25 percent had silicosis.

In 1923 [5] the mining companies of the Tri-State District of Oklahoma, Kansas, and Missouri, in cooperation with the Bureau of Mines and the Public Health Service, conducted a study of the mines in the district to determine whether the measures in use for the prevention of silicosis were adequate, and, if not, to recommend improvements. Of 309 miners examined, 94, or 30.4 percent, had definite silicosis, and an additional 114 were classed as doubtful. The investigation showed the mines of the Picher, Okla., district to be less dusty than those of the Joplin district. It was pointed out that the practices in the Picher mines had improved as a result of the Joplin study and recommendations. Recommendations to the mining companies included yearly medical examinations of all miners. This study led to the establishment of a clinic in Picher, cooperatively operated by the Bureau of Mines, the Public Health Service, Metropolitan Life Insurance Co., and the Tri-State Zinc and Lead Ore Producers Association.[6] Of the 27,553 individuals examined during the period 1927–32, 5,366 or 19.4 percent, had silicosis. Of the 5,366 with silicosis, 742 or 13.9 percent also had pulmonary tuberculosis.

On April 14, 1936, the Secretary of Labor, recognizing the confusion which existed at the time regarding silicosis, called the First National Silicosis Conference.[7] After a general discussion, the conference agreed to organize four committees to do at least three things: (1) study specific phases of the silicosis problem; (2) assemble in a series of reports the essential facts about silicosis; and (3) present specific suggestions for silicosis prevention and for straightening out other difficulties that silicosis had created. The reports of the committees served to clarify many aspects of the problem by defining the etiology of the disease, its relationship to tuberculosis, and the medical and engineering control methods. The conference was doubtlessly a motivating factor for silicosis control in the mining industry as well as other dusty trades.

During the period 1935–37, many of the larger mining companies in the Coeur D'Alene Mining District of Idaho started routine preemployment and periodic physical examinations of miners. Of 6,243 miners exposed to silica dust,[8] 2,328 miners or 37.3 percent had silicosis; 1,967 or 31.5 percent were classed as doubtful or presilicosis; 145 or 2.3 percent had both silicosis and pulmonary tuberculosis. Average dust levels encountered during rock drilling, crushing,

mucking, drawing chutes, and in airways ranged from 3.7 to 36.0 with an overall mine average (278 samples) of 16.7 million particles per cubic foot of air.

In 1939 the Utah State Board of Health collaborated with the Public Health Service and the Utah State Industrial Commission in a study of nonferrous metal mine workers.[9] Of 727 miners examined, 66, or 9.1 percent, had silicosis and 42, or 5.8 percent, had borderline silicosis. Nine, or almost 14 percent, of the workers with silicosis also had pulmonary tuberculosis.

Environmental data from the Utah survey showed that the underground worker was exposed to weighted average dust levels ranging from 3.8 million particles per cubic foot of air for station tender and carmen to 23.1 for miner, driller, and mucker, and 37.5 for bin tender, carloader, and chute gate tender. The median particle size as determined by impinger samples was 0.94 micron. Less than 1 percent of the metal miners were exposed to average dust concentrations higher than 30 million particles per cubic foot of air. Around 86 percent were exposed to dust concentrations between 6 and 30 million particles per cubic foot of air and around 12 percent were exposed to less than 6 million particles per cubic foot of air. It appeared that the average underground worker was exposed to atmospheric dusts containing 20–40 percent free silica. A number of methods had been instituted for minimizing the silica dust hazard including wet drilling, wetting of the muck piles, good underground ventilation, local exhaust ventilation, and good operational practices. It was observed that good practices in the proper use of the above methods to minimize dust reduced the dust levels 5-fold to 50-fold under levels existing during poor practices.

Data relating to 727 metal mine workers in the 1939 Utah study were grouped according to weighted average dust concentration in arbitrary intervals of 6 million particles per cubic foot of air. Each of these five dust concentration groups was subdivided into three durations of employment in metal mines, namely, less than 10 years, 10–19 years, and 20 years and over. There were no cases of silicosis in 39 miners who had worked at average dust levels under 6.0 million particles per cubic foot of air. Workers exposed to dust concentrations of 6.0–11.9 million particles showed no case of silicosis for the 44 men who worked less than 10 years, 1 case among the 36 men with 10–19 years, and 2 cases among the 18 men with service of 20 years and over. A study of employee work histories in this group indicated that dust exposures were likely very much higher for varying periods than the ranges shown here. Among persons exposed to 12.0–17.9 million particles the percentages with silicosis were 0, 7.0 and 19.0, respectively. With dust exposure of 18.0–23.9 million particles, silicosis increased markedly and was found in all duration

groups, progressing from 0.5 percent for those with less than 10 years, to 19.6 percent for 10–19 years, and 37.0 percent for 20 years and over. The highest exposure group, 24.0 and over million particles, showed silicosis prevalence of 3.4 percent, 18.4 percent, and 68.2 percent.

In following up the recommendations of studies made in the Tri-State Mining District of Oklahoma, Kansas, and Missouri during the period 1917–32, the Tri-State Zinc and Lead Ore Producers Association in 1936 employed an air hygiene engineer to conduct routine dust counting surveys in companies desiring this service. Included in dust control measures in the mines were: wet drilling, wetting the muck and workfaces before shoveling and drilling, wetting of haulageways, blasting at the end of workshift, and ventilation. During the first 4-year period, the air hygiene engineer took over 4,000 air samples for dust.[10] Seventy-six percent of the dust samples collected during the first year were under 5.0 million particles per cubic foot of air. During the fourth year 88 percent of the samples were under 5.0 million particles. Since not all the companies were using the services of the air hygiene engineer, a survey was made during the fourth year to determine whether there was a difference in the degree of mine dustiness based upon whether or not routine dust sampling was done in the mine. Drillers, shovelers, and drag operators had respective average dust levels of 1.6, 2.2, and 2.4 million particles per cubic foot of air in mines conducting routine dust sampling compared to respective averages of 6.6, 4.3, and 7.4 for mines without routine dust sampling services. This clearly points out the usefulness of routine monitoring of dust levels in the mines since it offers a check on proper and efficient use of dust control measures.

The onset of World War II greatly curtailed the attention given to research concerning the problem of silicosis among metal mine workers. This resulted in a dearth of published information on this subject between that period and the start of the current study.

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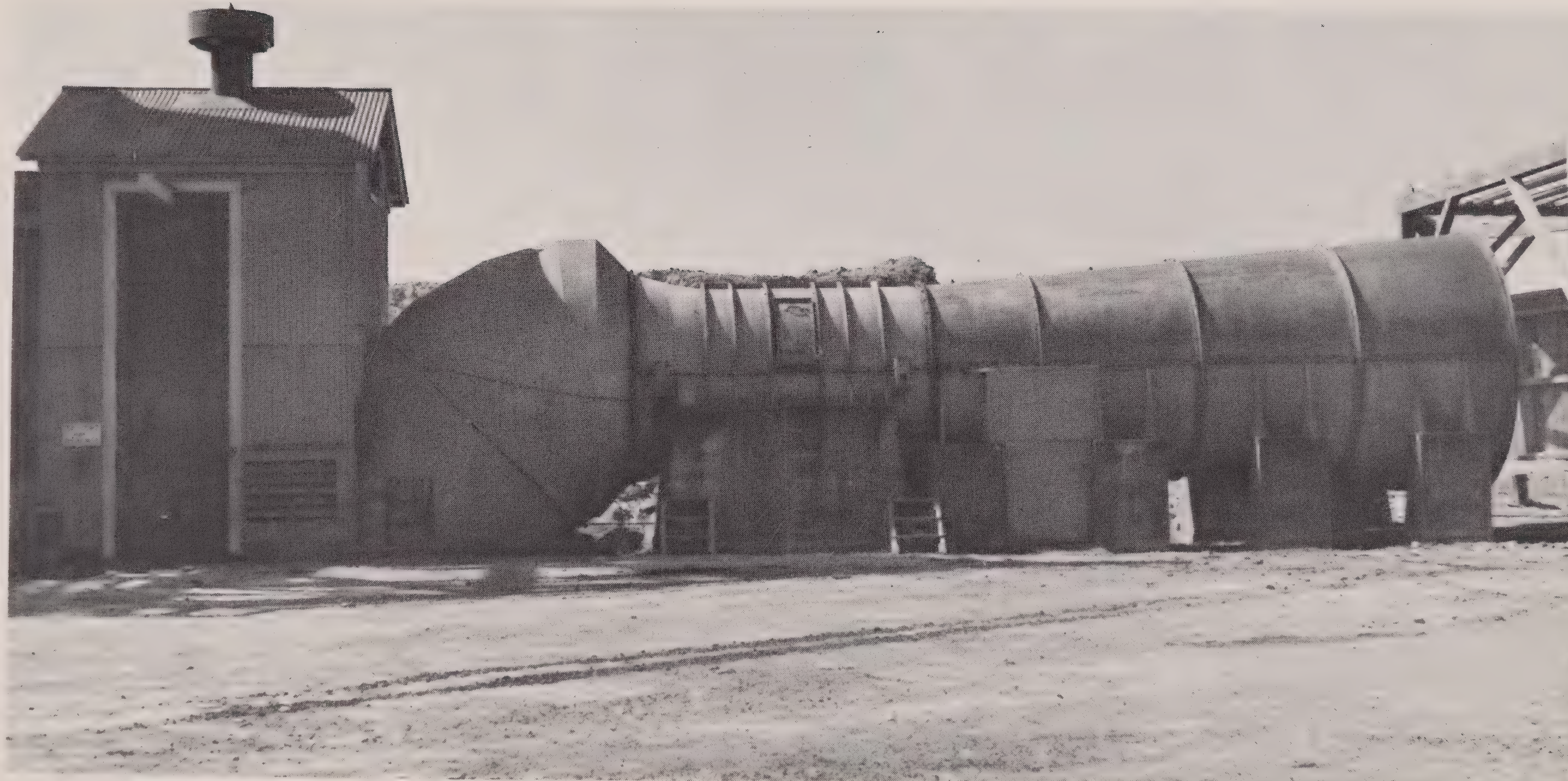


Two-stage 500-horsepower main surface fan—direct expulsion type.
(Courtesy of The Anaconda Co., 1963.)

CHAPTER IV

The Enviromental Study

Part A—Field Investigation

PURPOSE AND SCOPE

The purpose of the engineering phase of the study was to assess the working environment in a representative segment of the Nation's underground metal mines, with particular attention to airborne dust.

When the study was started in the spring of 1958, approximately 35,000 men were employed at 2,000 underground metal mines in the United States. About 25,000 men were employed underground, and 10,000 were employed in associated surface areas such as shops, crushers, mills, and other locations.

The environmental study, which was completed in the fall of 1961 included 67 mines chosen on the basis of characterizing factors such as commodity, geology, mining district, mining method, and size. These mines were operated by 46 different companies and represented employment of approximately 14,000 underground and 6,500 surface workers. Thus, although the number of mines included in the study was only a small fraction of the mines operating at the time, the number of men employed at these mines represented almost 60 percent of the nationwide employment at underground metal mines. Table IV.1 presents data on the mines included in the study.

TABLE IV.1.—*Data on mines included in the dust study*

Commodity group	Mines	Underground employees	Surface employees	Total employees
Total	67	14, 010	6, 500	20, 510
Iron	14	3, 267	964	4, 231
Copper	11	5, 072	2, 188	7, 260
Lead-zinc-silver	22	3, 260	1, 021	4, 281
Uranium	8	325	48	373
Miscellaneous	12	2, 086	2, 279	4, 365

Data collected in the underground study included determination of concentrations of airborne dust, particle-size distribution analyses, and determination of free silica in samples of airborne and settled dust and dust-source materials. Semiquantitative spectrographic examination of these materials was made as a matter of record in the event the data would be needed to explain other findings of this or future studies. Data were obtained also on dust control methods, ventilation, and composition of mine atmospheres. Measurements of barometric pressure, temperature, and humidity were made as a matter of record, but results are not included in this report. Measurements were made of natural underground ionizing radiation, but since no levels of consequence were observed in any working place, results are not reported.

The sampling method was designed basically to indicate the time-weighted average dust exposures of underground employees in the conduct of specific and typical operations. The weighted average exposure represented the average dust concentration, expressed in millions of particles per cubic foot of air (mppcf), to which an employee was exposed over an entire working shift. To make this determination, the workman being observed was followed during the complete shift and samples of airborne dust were collected in his breathing zone at 30-minute intervals. The time-weighted average concentration of all samples was then calculated, taking into account the different activities involved throughout the shift in conducting the observed operation. The procedure may be represented by the equation—

$$D_{wa} = \frac{(d_1 \times t_1) + (d_2 \times t_2) + \ . \ . \ . \ + (d_n \times t_n)}{T}$$

in which

D_{wa} = full-shift weighted average dust exposure, mppcf

d_1, d_2, d_n = average dust exposures during each activity comprising the full shift, mppcf

$t_1 t_2, t_n$ = time spent in each activity comprising the full shift, hours

T = total time of shift, hours

$= t_1 + t_2 + \ . \ . \ . \ + t_n$

The underground sampling procedure was designed to obtain enough weighted averages to insure that the study was representative of conditions and operations at each mine. The minimum number of places and operations to be sampled in a mine was based upon the following criteria:

1. At least 20 percent of all locations at which ore or waste was produced.
2. At least two of each type of working place. For example, if four drifts were working, at least two (50 percent) would

be sampled. If three raises were working, at least two (66.7 percent) would be sampled. If only two stopes were operating, both would be sampled. As a result, the smaller mines usually would yield a larger number of samples in proportion to number of employees than would the larger mines. In several of the smaller mines every ore-producing place (usually only two or three) was sampled.

3. Any other location in which sampling was necessary to obtain representative data.

In addition to these observations underground, samples of airborne dust representative of the working environment were collected in the surface installations that were considered to be parts of the mine properties. The effects of surface weather conditions were not evaluated because each mine was surveyed but once even though studies were conducted in all seasons of the year.

GEOGRAPHY AND GEOLOGY OF ORE DEPOSITS

Locations of the mines included most mining areas of the continental United States. Surface elevations ranged from approximately 500 feet to 11,000 feet above sea level. Most metals mined in the United States were represented in the study. Geologic information was based principally on data received from the mine operators. Table IV.2 relates the host rock with alpha quartz analyses. These analyses were used to determine the members of each group in the table.

TABLE IV.2.—*Host rock and alpha quartz correlation*

Group	Host rock	Commodity	Alpha quartz, bulk samples, percent [1]
1	Andesite, calcite gangue	Gold, silver	95
2	Quartzite, quartz monzonite	Gold, silver, copper, lead, zinc, cobalt, molybdenum, mercury.	21–75
3	Schist, slates, shales	Gold, silver, copper, lead	4–54
4	High silica limestone, dolomite.	Gold, silver, copper, lead, zinc, molybdenum, mercury, iron, tungsten.	9–67
5	Rhyolite, granite	Molybdenum, manganese, mercury.	9–60
6	Chert, opalite	Mercury, iron	2–10
7	Basalt, peridotite	Copper, chromium	<1–12
8	Low silica limestone	Copper, lead, zinc, iron	<1–9
9	Predominately sandstone	Uranium, vanadium	42–95

[1] Composite ore sample; assay sample over 30-day period.

The study included mines producing virtually every metal mined in significant commercial quantities in the United States. No apparent relationship was found between dust concentrations and the commodity being mined.

MINING METHODS

Two or more mining methods, or modifications of methods, frequently were used at the same mine; however, one principal stoping method usually was characteristic of each mine. Various mining methods are described in detail by Jackson and Hedges,[1] * Jackson and Gardner,[2] Peele,[3] and Bucky.[4] Underground operations other than stoping included exploration, development, material handling, transportation, and maintenance. Distribution of mines by principal mining method is shown in table IV.3.

TABLE IV.3.—*Distribution of 67 mines according to principal mining method*

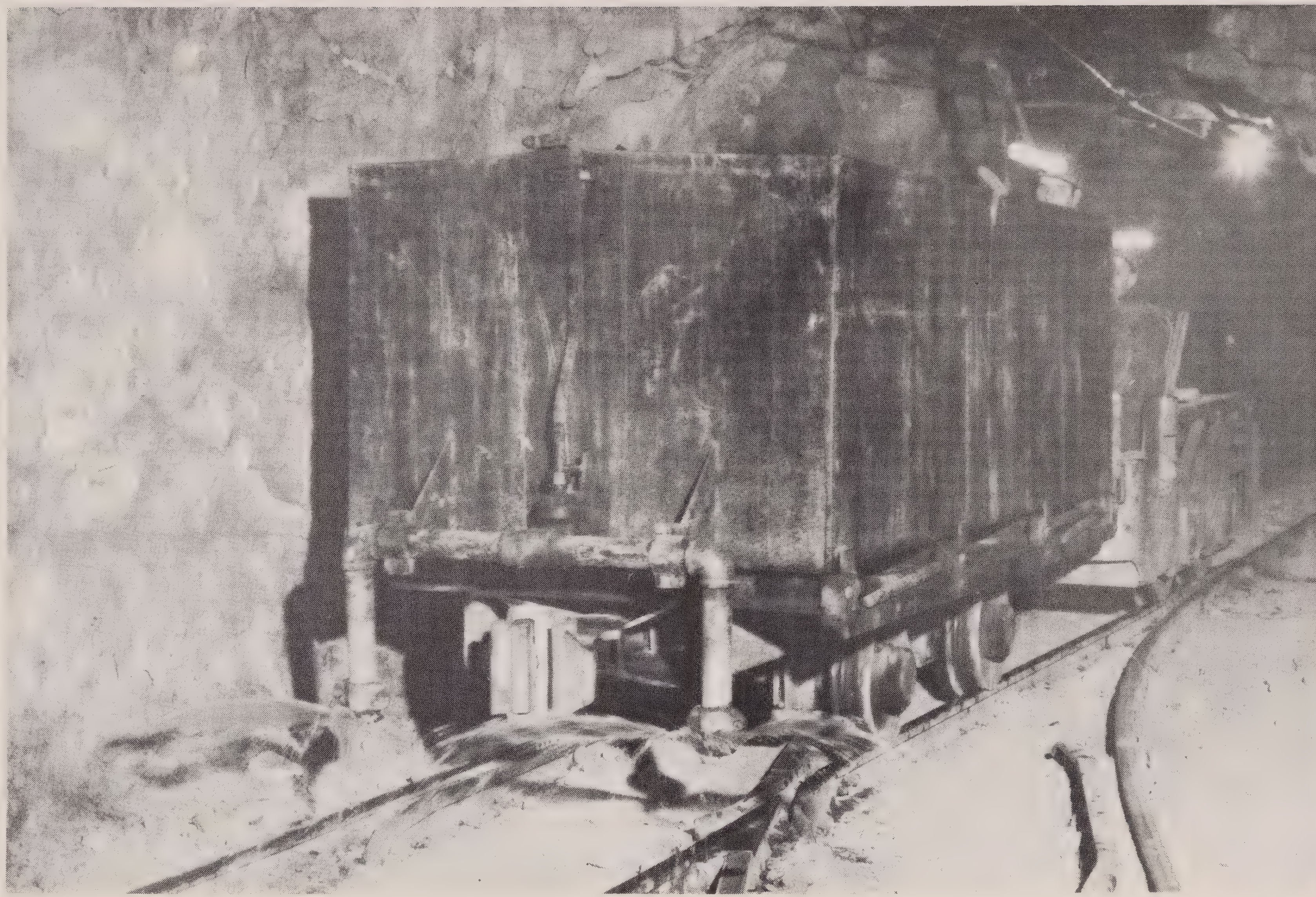
Mining method:	*Number of mines*
Block caving	9
Open stopes	6
Sublevel stopes	9
Room and pillar	16
Shrinkage stopes	3
Cut-and-fill	10
Square set	11
Top slicing	1
Development only	1
Pumping only	1

SURVEY METHODS

The midget impinger [5] [6] was the standard instrument used for sampling airborne dust. This instrument was used for several reasons:

(a) The impinger has been used as the dust-assessing instrument in most major studies in the United States in which prevalence of silicosis has been correlated with concentrations of airborne dust to which workers have been exposed. As these studies date back more than 25 years, and have served in large part as the basis for promulgation of threshold limit values for dust in occupational environments, adherence to use of the impinger in the current study would permit a comparison of results with the findings of past investigations.

*Numbers refer to reference list at the end of the chapter.



Sprinkler tank car for wetting haulageways. Rear view. (Courtesy of The Anaconda Co., 1963.)

(b) The Bureau of Mines, the Public Health Service, and other agencies have used the impinger in studies of dust conditions in the mining and mineral industries for many years, and a large amount of information on dust concentrations in terms of impinger results has been accumulated in the course of these studies.

(c) Most mining companies in the United States that conduct dust surveys have used the impinger in evaluating dust conditions and dust control methods. Thus, use of the impinger in the current study would facilitate interpretation of results by company personnel concerned with dust control.

Although the midget impinger was used as the standard dust sampling instrument, field and laboratory research was conducted collaterally to compare results with results obtained by other methods. A brief history of atmospheric dust sampling and evaluation is presented in another section of this report.

Dust concentrations (mppcf) were determined from samples collected with the midget impinger using redistilled, dust-free, ethyl alcohol as the collecting medium. Portions of the collected samples were counted in Sedgwick-Rafter cells by a light-field method and using a midget microprojector [7] fitted with a zirconium arc lamp with iris diaphragm.[8] Settling time for dust particles in the cells before counting was 30 minutes. Particles larger than 5 microns as measured in a horizontal plane were not counted. Limits for acceptance of agreement between counts on two cells representing an individual sample were determined by use of the curves shown in figure IV.1.

Samples of airborne dust for particle-size distribution determination were collected on cellulosic membrane filters held in a brass filter holder attached to a midget impinger pump. Fifty-five of these samples were evaluated by use of both an optical microscope and an electron microscope.

Quantitative free silica (alpha quartz) analyses were made by the X-ray diffraction method described by Ballard, Oshry, and Schrenk [9] using modern equipment. These analyses included (a) airborne dust collected by high-volume samplers in ore transfer areas in mines and crusher areas in mills, where enough airborne dust was present to permit collection of samples in the amount required for analysis; (b) settled dust from mine and mill walls, timbers, rafters, and equipment; (c) composites of assay samples representing mine ore. The emission spectrograph [10] was used to analyze samples semiquantitatively for metallic elements.

Mine atmospheres were sampled with vacuum type air-sample containers [11] for determination of carbon dioxide, oxygen, and ni-

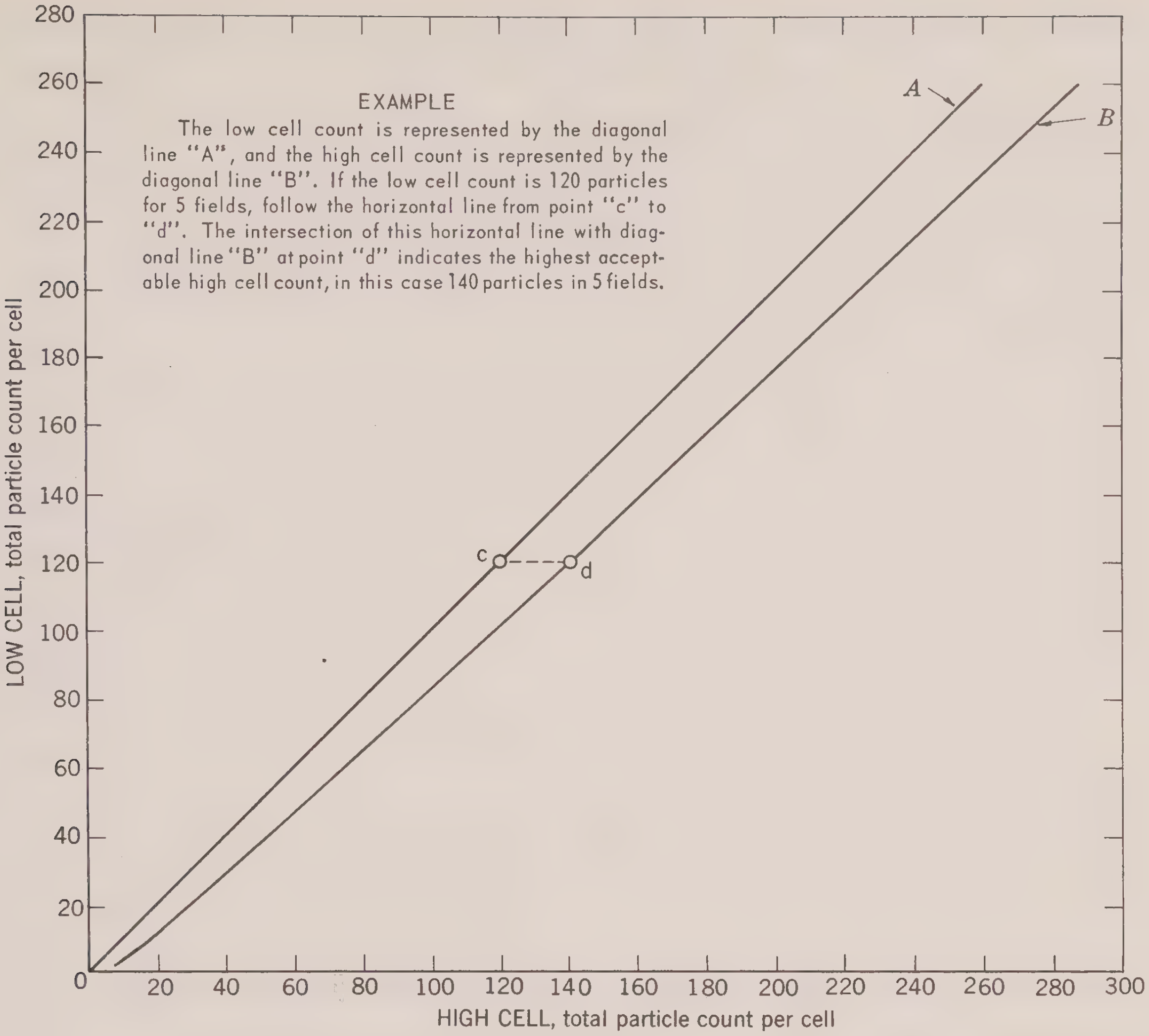


FIGURE IV.1.—Acceptable counts for two cells from the same sample.

trogen by use of gas-volumetric type apparatus[12] and for determination of carbon monoxide by a sensitive colorimetric method.[13] Total oxides of nitrogen (except nitrous oxide) were determined by the phenoldisulfonic acid method.[14] At the time of the study, portable instruments specific for determination of nitrogen dioxide were not available for field use. Check tests for carbon monoxide were made in the field by use of portable instruments.

Field Procedures

The size of the field party and number of days required to complete the study at each mine were estimated from preliminary data obtained from each mining company. The number of men employed was used to make a rough estimate of the number of impinger samples to be collected. However, the actual number collected at each mine was dependent on conditions, the intent being to obtain sufficient samples to assure that results were representative of all conditions at the mine.

While some members of the field party set up a temporary laboratory at each mine, others obtained information of a general nature, including size of mine, number of employees, production, and other necessary data. After surface and underground working places were observed, sampling locations were selected to represent all routine working conditions. At least 20 percent of each type of underground operation was sampled; in smaller mines a larger percentage of working places was sampled. All sampling locations were chosen by Bureau of Mines personnel.

Midget impinger samples of airborne dust in underground working places were collected either in the workmen's breathing zones or as close as practicable to their breathing zones. These samples were taken generally at 30-minute intervals during the entire shift, and included all activities comprising the operation that the workman was performing. Results of these samples provided the basis for calculating a time-weighted full-shift average dust exposure relating to each operation studied.

Three or four midget impinger samples were collected at each surface location where men were employed, and in underground locations such as skip pockets, dumping points, and repair shops. Experience indicated that dust concentrations in these locations did not fluctuate sufficiently to warrant full-shift sampling.

At the start of the study approximately 1,300 midget impinger samples were counted in the field laboratory within 24 hours of collection, and recounted in the Bureau of Mines Denver laboratory 1 to 3 weeks after collection. Comparisons between field laboratory counts and Denver laboratory counts indicated that the average variation was less than 4 percent.

Throughout the study approximately 25 percent of the midget impinger samples collected at each location were counted in the field laboratory within 24 hours of collection. At the completion of the survey at each mine, dust concentrations determined from these samples were used as a basis for verbal discussions with mine officials. The remaining samples were counted in the Denver laboratory.

A total of 18,079 midget impinger samples of airborne dust was collected; 14,837 underground and 3,242 on the surface. Table IV.4 shows the distribution of the samples in respect to location or operation.

In addition to the midget impinger samples, numerous samples were taken for free silica analyses, particle sizing, air quality analyses, and other special data. Table IV.5 lists all samples collected during the study.

TABLE IV.4.—*Number of midget impinger samples collected for determination of airborne dust concentrations*

Location or operation	Samples	
	Number	Percent
Total	18, 079	100. 0
Stopes	6, 701	37. 1
Drifts	2, 171	12. 0
Raises	899	5. 0
Grizzlies	120	. 7
Underground hoists	202	1. 1
Skip and chutes	546	3. 0
Motor crews	1, 430	7. 9
Exploration drilling	205	1. 1
Timbermen	1, 149	6. 4
Trackmen	126	. 7
Repairmen underground	229	1. 3
Gunite and concrete crews underground	200	1. 1
Miscellaneous mobile equipment underground	285	1. 6
Miscellaneous employees underground	114	. 6
Maintenance and repair (surface)	1, 114	6. 2
Crushers (underground and surface)	459	2. 5
Mills (underground and surface)	1, 145	6. 3
Assayers	196	1. 1
Hoistmen (surface)	159	. 9
Topmen	94	. 5
Operating miscellaneous equipment (surface)	23	. 1
General air (intake and return airways)	368	2. 0
General air (surface)	144	. 8

TABLE IV.5.—*Samples collected during the study*

Type	Number	Purpose
Total	19, 974	
Midget impinger	18, 079	Dust concentration
Airborne dust	82	Free silica
Settled dust	234	Free silica
Bulk (ore)	82	Free silica
Cellulosic filter	481	Particle size
Cellulosic filter	307	Radiation
Vacuum bottle	614	Air quality
Thermal precipitator	95	Comparison with midget impinger

Through the years those concerned with the health of workers in industry have endeavored to develop information on concentrations of atmospheric contaminants that may exist in industrial working environments without producing ill effects upon workers as a result of their occupational exposures. Such information has been developed through laboratory research and through studies in various industries where medical examinations of workers have been used to correlate their health status with the extent of contamination of the atmospheres in which they have worked. Such information has been made available, through various means, to those responsible for maintaining suitable working conditions in industry to provide them with guidelines to follow in establishing effective control measures.

At the first annual Conference of Governmental Industrial Hygienists (now the American Conference of Governmental Industrial Hygienists) in 1938, it was decided that "one of the important objectives of the conference would be to collect and make accessible to all industrial hygiene workers such information and data as might be of assistance to them in proper fulfillment of their duties." [15]

The first list of maximum allowable concentrations compiled by the conference was presented in 1942, and consisted merely of an assembly of information available at the time. This first list was presented without comment as to the validity of the data.

A more formalized list of maximum allowable concentrations or "threshold limit values" was issued by the American Conference of Governmental Industrial Hygienists in 1946.[16]

This list was issued with the definite understanding that it be subject to annual revision, a policy which has been continued by the conference. This list contained the following suggested threshold limit values for mineral dusts:

- High silica (above 50 percent free silica, SiO_2)—5 million particles per cubic foot of air.
- Medium silica (5–50 percent free silica, SiO_2)—20 million particles per cubic foot of air.
- Low silica (below 5 percent free silica, SiO_2)—50 million particles per cubic foot of air.

When the study of dust conditions in metal mines was started by the Bureau of Mines in 1958 these threshold limit values were still in effect [17] and were the guidelines suggested to mine managements during the field study. At the 1962 meeting of the American Conference of Governmental Industrial Hygienists new threshold limit values were adopted.[18] Reasons for the change in threshold limit values are to be published by the American Conference of Govern-

mental Industrial Hygienists. These new values were based upon the formula:

$$\text{TLV, mppcf} = \frac{250}{\%\text{SiO}_2 + 5}$$

to express threshold limit values in terms of millions of particles per cubic foot of air. In this formula free silica content refers to airborne dust. The American Conference of Governmental Industrial Hygienists emphasizes that the values "should be used as guides in the control of health hazards and should not be regarded as fine lines between safe and dangerous concentrations. They represent conditions under which it is believed that nearly all workers may be repeatedly exposed, day after day, without adverse effect. The values refer to time-weighted average concentrations for a normal workday."[18]

Both the 1958 and 1962 threshold limit values are used in this report merely as bases or guidelines for subsequent discussions, and are not intended to represent inflexible boundaries or lines of division between conditions found in the mines studied, nor does their use in this report necessarily represent endorsement by the Public Health Service or the Bureau of Mines.

The threshold limit values for siliceous dusts suggested by the American Conference of Governmental Industrial Hygienists relate to time-weighted average concentrations that represent exposure throughout a normal workday. The weighted average exposure is derived from the results of multiple samples collected throughout the workday, each sample being weighted according to the proportion of the workday that it represents. The sum of these weighted values is the time-weighted average exposure. An individual dust concentration determined in such a group of samples cannot be considered, of itself, as being above or below the threshold limit value. However, the threshold limit value provides the only logical baseline, or point of reference, for considering the potential of each sample in contributing to the weighted average exposure. For this reason individual samples that could contribute significantly to weighted average exposures exceeding the 1962 American Conference of Governmental Industrial Hygienist threshold limit value are designated in this report as representing "excessive dust."

In areas where experience demonstrated that dust concentration did not vary significantly throughout the workday, the arithmetic average dust concentration was determined by multiple sampling during the workday. Such arithmetic averages are considered in this report in the same sense as time-weighted averages.

Miner operating electric tugger in slushing operation. (Courtesy of The Homestake Mining Co., 1963.)

RESULTS OF ENVIRONMENTAL STUDY

Particle Size

Particle-size determinations by optical microscopy were made from 481 cellulosic membrane filter samples, usually collected in the breathing zone of surface and underground workers performing routine operations. Fifty-five of these samples were divided each into two sections, one section being evaluated by the optical microscope, the other section being evaluated by the electron microscope. A microprojector with ruled screen and a 1/12a, 1.32 N.A., oil-immersion objective afforded a total magnification of 10,000 for optical microscope determinations, with a resolution of about one-fourth micron. Comparative determinations of particle-size distribution were obtained by use of the electron microscope with magnification of 9,000 to 10,000 diameters with a resolution of about 0.005 micron.

Table IV.6 shows a comparison of results obtained by optical and electron microscopy. Statistical correlation between companion geometric mean diameters determined on the same samples by electron and optical microscopy was inconclusive, and the standard deviations yielded by the two methods were seldom in agreement. Nevertheless, the median geometric mean diameter determined for each group of samples by electron microscopy, with a resolution of 0.005 micron, is very near in value to the corresponding median determined by optical microscopy. Thus, even though good statistical correlation between results by the two methods was not found, it can be concluded from the comparison of medians that there was not a preponderance of submicron particles too small to be detected by optical microscopy in the samples examined.

TABLE IV.6.—*Comparison of 55 particle-size analyses by electron and optical microscopy*

Number of Samples	Operation	Median of geometric means, micron	
		Optical microscope	Electron microscope
19	Drilling	0. 37	0. 33
8	Slushing	. 36	. 42
7	Mucking	. 38	. 33
4	Air cleaner intake	. 39	. 64
3	Air cleaner exhaust	. 40	. 38
3	Crushing	. 29	. 34
11	Miscellaneous	. 35	. 25

Table IV.7 shows the frequency of occurrence of ranges of geometric mean particle diameters for the 481 samples sized by optical microscopy. Figure IV.2 shows the same data in graphic form. The median geometric mean diameter for the 481 samples was 0.36 micron. Almost 80 percent of the samples yielded geometric mean diameters within the range of 0.26 to 0.45 micron, that is, within ±0.10 micron of the median value; and almost 95 percent of the samples had geometric mean diameters of 0.50 micron or smaller. It is of interest to note that the medians of geometric means determined by optical microscopy for various operations as shown in table IV.6 are, with one exception, within ±0.05 micron of the median value for all 481 samples.

Standard geometric deviation was quite variable within each range of geometric mean particle diameter as shown in table IV.7. In general, the range of standard geometric deviation decreased with increasing geometric mean particle diameter. The variability from one sample to another of both geometric mean diameter and standard deviation made impractical any effort to predict the concentration of submicron particles for any operation or group of samples on the basis of particle-size results and impinger counts.

In general, examination of the samples collected indicated ranges of particle sizes that included appreciable portions of all sizes that would be retained in the alveolar spaces of the lungs.

TABLE IV.7.—*Particle-size characteristics of 481 samples examined by optical microscopy*

Number of samples	Frequency of occurrence, percent	Range of geometric means, micron	Range of standard geometric deviations
40	8. 31	0.25 and smaller	1. 87–4. 49
61	12. 68	0. 26–0. 30	1. 65–3. 93
130	27. 03	0. 31–0. 35	1. 60–4. 25
122	25. 36	0. 36–0. 40	1. 50–3. 59
68	14. 14	0. 41–0. 45	1. 52–3. 26
35	7. 28	0. 46–0. 50	1. 74–3. 33
10	2. 08	0. 51–0. 55	2. 19–3. 24
7	1. 45	0. 56–0. 60	2. 32–3. 14
5	1. 04	0. 61–0. 65	2. 36–2. 76
2	. 42	0. 66–0. 70	2. 51–2. 60
1	. 21	0. 71–0. 75	2. 82

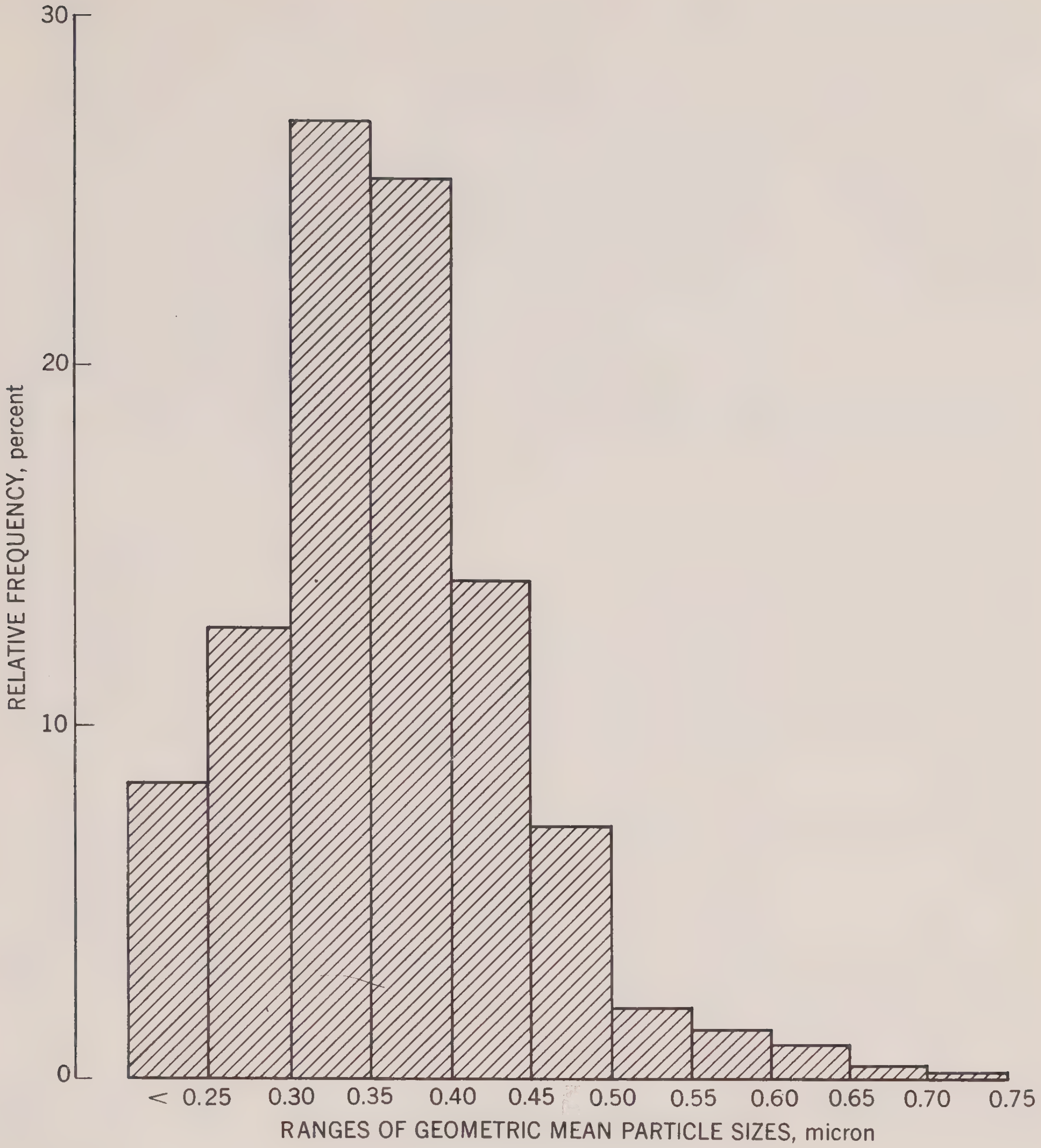


FIGURE IV.2.—Frequency distribution of geometric mean particle sizes.

Free Silica Content of Dust

Eighty-two samples of airborne dust, 234 samples of settled dust, and 82 bulk (ore) samples were collected and analyzed for free silica (alpha quartz) content during the study. The samples of airborne dust were collected with a high-volume sampler which was operated by a 110-volt motor and therefore could be used only at locations where a suitable power supply was available. Consequently, most of the samples of airborne dust were collected either in mill and crusher buildings on the surface, or at underground locations such as shaft stations and dumping points. These samples were of necessity collected during rather short intervals and may not have been representative of continuing conditions. In some

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mines it was not possible to collect enough airborne dust for analysis within a reasonable time, even with the high-volume sampler.

The samples of settled dust were collected more generally throughout the working areas of all the mines studied, and represented dust generated by the mining operations over extended periods of time. Only the portions of these samples that passed a 325-mesh screen were analyzed for free silica. The bulk samples were, in most instances, composites of ore assay samples and possibly contained inordinate proportions of materials that would not become airborne. Of the samples of airborne dust that were analyzed for free silica content, about half the results were in close agreement (exact or within plus or minus 2 percent) with the analyses of settled dust from the same mines.

The results of the analyses of the 234 settled dust samples which were taken in the 67 mines were used to classify the mines in respect to free silica and as the bases for determining the threshold limit values applicable at each mine. Table IV.8 shows the number of mines in the various free silica ranges, and the distribution of employment among these groups of mines.

TABLE IV.8.—*Free silica content of settled dust at 67 mines*

	Ranges of free silica, percent							
	0–5	5–10	10–20	20–30	30–40	40–50	Over 50	Total
Number of mines	9	11	16	12	10	5	4	67
Percent of mines	13. 4	16. 4	23. 9	17. 9	14. 9	7. 5	6. 0	100. 0
Number of men	1, 972	2, 536	4, 606	4, 354	6, 624	201	217	*20, 510
Percent of men	9. 6	12. 4	22. 4	21. 3	32. 3	1. 0	1. 0	100. 0

*More than 50 percent of nationwide employment at underground metal mines in underground and surface operations at time of study.

Figure IV.3 indicates the percentage of the midget impinger samples in the various free silica ranges.

Dust Concentrations

During the study 789 full-shift weighted average exposures in underground operations were determined, involving collection of 14,480 midget impinger samples. These determinations were based upon full-shift sampling of the environment of individual workmen engaged in various mining operations, taking into account the different activities involved in each such operation, and time-weighting each activity in respect to the overall operation. The full-shift

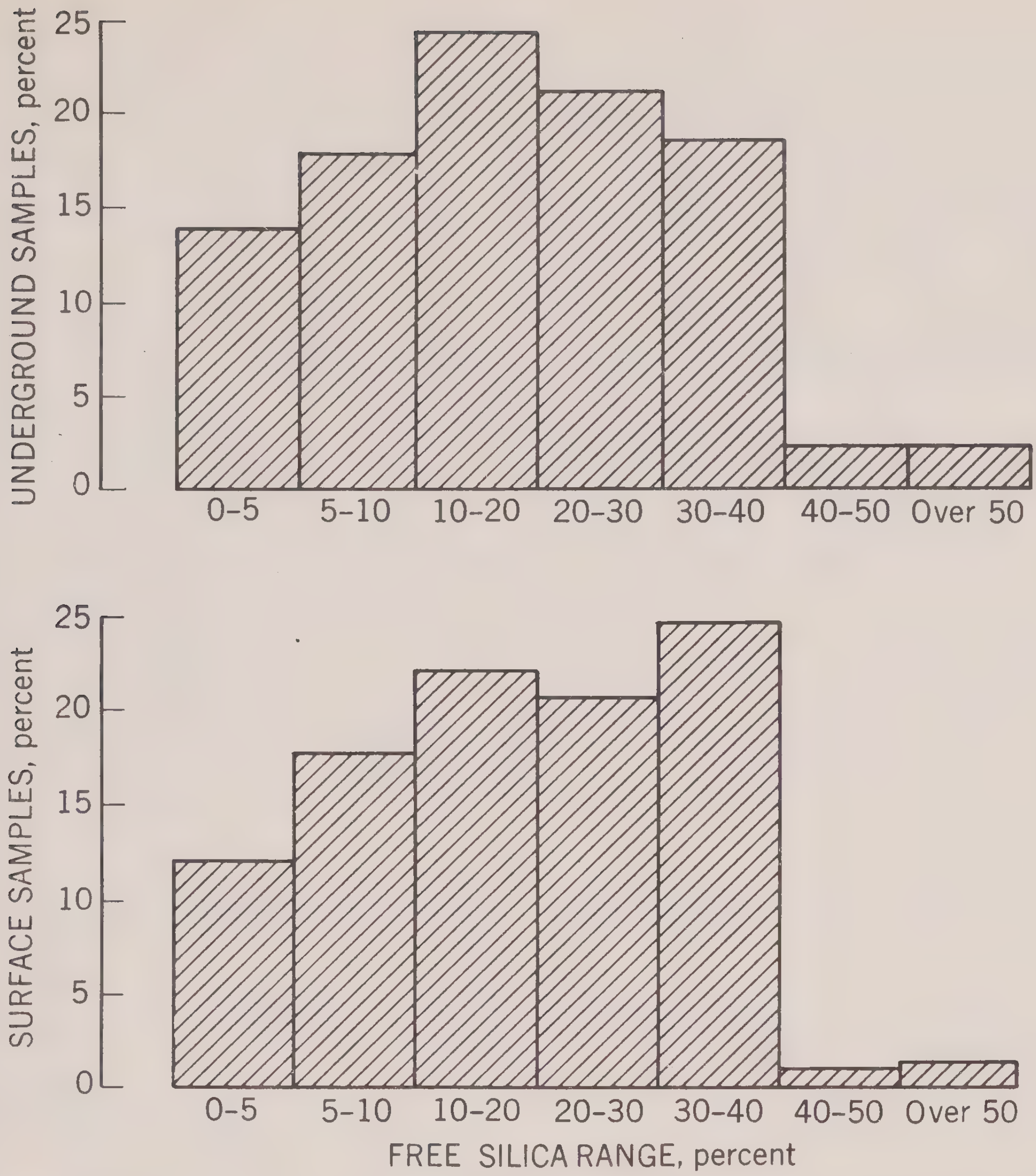


FIGURE IV.3.—Percentage distribution of midget impinger samples by range of free silica content.

sampling provided a representative evaluation of dust exposures related to specific operations, but it is emphasized that results of the full-shift determinations apply only to operations, as such, and are not meant to classify the total underground mining population into various degrees of dust exposure. It may not be assumed that distribution of men among the various operations has been or will continue to remain constant throughout the industry. Moreover, evaluations on the full-shift basis represented conditions existing only at the time of sampling and may not be considered indicative of past or future conditions.

Figure IV.4 shows the 789 weighted average exposures in the 67 mines studied, plotted to indicate weighted average dust concentration and free silica content in relation to both the threshold limit values in effect in 1958–61, when the study was conducted, and those adopted by the American Conference of Governmental Industrial Hygienists in 1962. Based upon the 1958–61 threshold limits, 44, or 5.6 percent, of the weighted average exposures exceeded the lim-

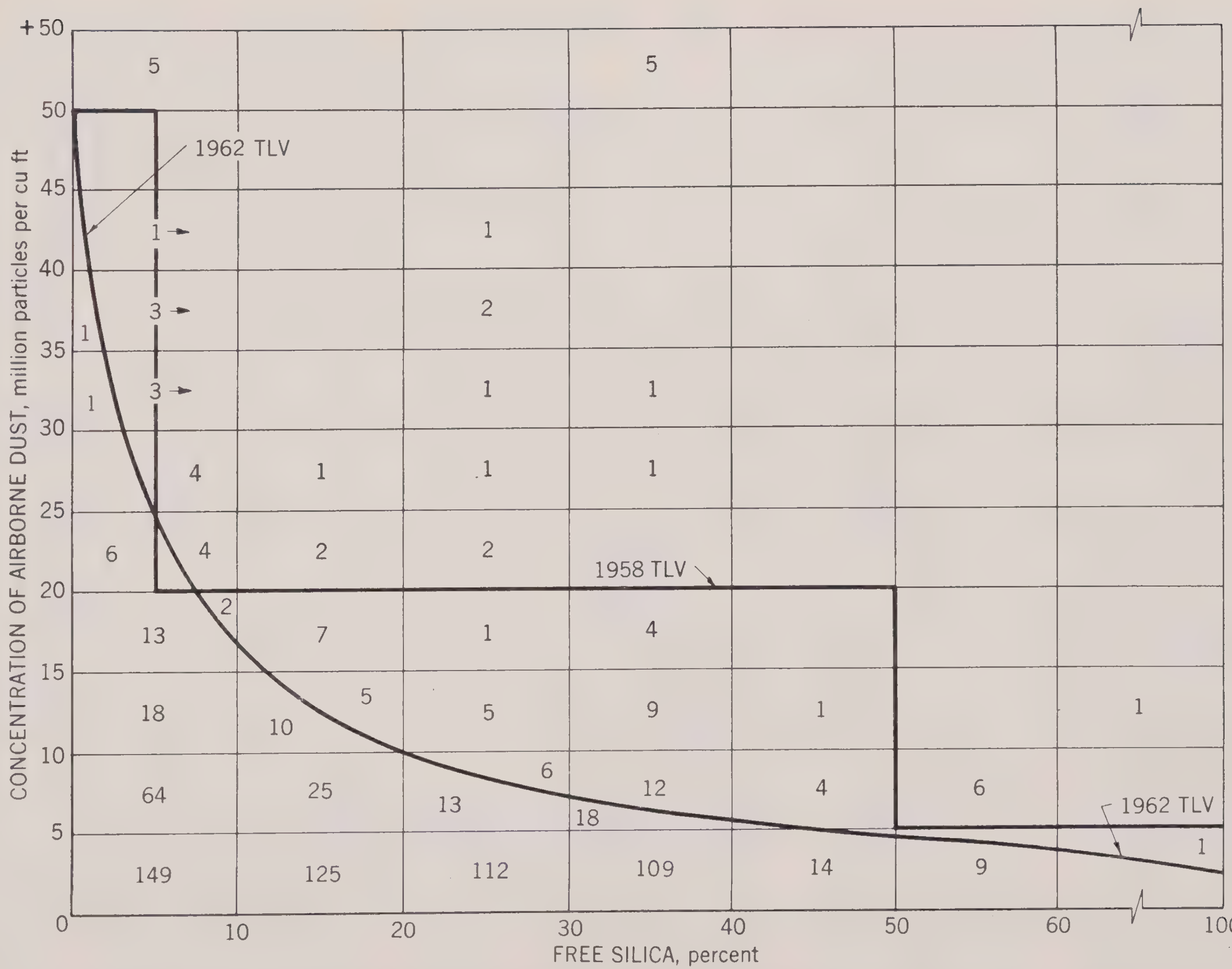


FIGURE IV.4.—Distribution of weighted average exposure underground in respect to threshold limit values.

its; whereas, on the basis of the 1962 threshold limits, 104, or 13.2 percent, of the weighted averages were above the threshold limits.

Table IV.9 shows results of the full-shift weighted average exposure determinations in relation to the threshold limit values in effect during the study, 1958–61, and to those adopted by the American Conference of Governmental Industrial Hygienists in 1962. In the table the 67 mines studied are grouped according to frequency of occurrence of weighted averages above the respective threshold limits. In respect to either set of threshold limit values, the data in table IV.9 show that a few mines contributed a major portion of the full-shift weighted averages that exceeded the limits. The table also shows distribution of the underground mining population at the time of the study and distribution of the 789 weighted average determinations among the groups of mines.

It is emphasized also that although some mines had no weighted average exposures in excess of suggested limits, some individual impinger samples in all the mines studied contained excessive dust, showing that improved dust control was needed at these particular spots.

TABLE IV.9.—*Distribution of weighted average exposures that exceeded threshold limit values**

Mines studied		Underground mining population		Weighted average exposures over threshold limit values			Weighted average exposures determined	
Number	Percent of total	Number of men	Percent of total	Per mine	Total	Percent of total	Number	Percent of total
On basis of 1958–61 threshold limits								
46	68. 6	8, 629	61. 5	0	0	0	499	63. 2
13	19. 4	3, 041	21. 7	1	13	29. 6	175	22. 2
3	4. 5	856	6. 1	2	6	13. 6	37	4. 7
2	3. 0	316	2. 3	3	6	13. 6	21	2. 7
1	1. 5	316	2. 3	4	4	9. 1	16	2. 0
2	3. 0	852	6. 1	5 and over	15	34. 1	41	5. 2
67	100. 0	14, 010	100. 0	--------------	44	100. 0	789	100. 0
On basis of 1962 threshold limits								
30	44. 8	4, 821	34. 5	0	0	0	293	37. 1
14	20. 9	2, 989	21. 3	1	14	13. 5	179	22. 7
10	14. 9	1, 136	8. 1	2	20	19. 2	100	12. 7
5	7. 5	804	5. 7	3	15	14. 4	52	6. 6
2	3. 0	417	3. 0	4	8	7. 7	28	3. 5
6	8. 9	3, 843	27. 4	5 and over	47	45. 2	137	17. 4
67	100. 0	14, 010	100. 0	--------------	104	100. 0	789	100. 0

*Of 789 full-shift weighted average exposures determined in 67 mines, 44, or 5.6 percent, exceeded the 1958–61 threshold limit values; and 104, or 13.2 percent exceeded the 1962 threshold limits.

Miner wetting down muck pile and faces prior to mucking operation. Note overhead vent tubing and method of ground support. (Courtesy of The Anaconda Co., 1963.)

Underground—General

Although the average concentration of dust in all samples collected at an underground mine has little or no bearing on the exposure of an individual miner, this "mine average" may be useful as a measure of the effectiveness of dust control.

Figure IV.5 shows the averages of all midget impinger samples collected underground at each mine in respect to dust concentration and free silica content.

Figure IV.6 shows the distribution of all midget impinger samples collected underground in respect to dust concentration and free silica content.

No marked differences were evident in the distribution of airborne dust concentrations in the mines in the different free silica ranges. This indicates, in general, that the same degree of attention was being given to dust control in low silica mines as in high silica mines.

Underground Operations

The type of mining method employed usually has an important effect on production of dust, and therefore has a bearing on dust control procedures required. Selective mining usually requires smaller equipment and results in a lower tonnage per employee than full scale mining, such as in block caving.

Table IV.10 is a summary of underground occupations for which 8-hour weighted average exposures were calculated. This summary included miners in stopes, raises, and drifts. Transportation employees included haulage crews, diesel truck drivers, shuttle car operators, and hand trammers. Maintenance and construction employees included concrete crews, gunite crews, and motor grader operators. Other employees included were exploration drillers, rock bolters, and shaft, station, winze and sump miners.

Table IV.15 gives additional data on individual sample groups.

Figure IV.7 shows the percentage of midget impinger samples in the various ranges of dust concentration for each principal underground operation, as well as for some miscellaneous mining operations not readily classified in respect to mining method.

Of the 14,837 results of impinger samples shown in figure IV.6, 1,440 samples, or slightly less than 10 percent, are considered to represent excessive concentrations of dust. Discussion of these 1,440 samples, and conditions contributing to the excessive concentrations, is essential in order that proper recommendations may be made for correction of these conditions.

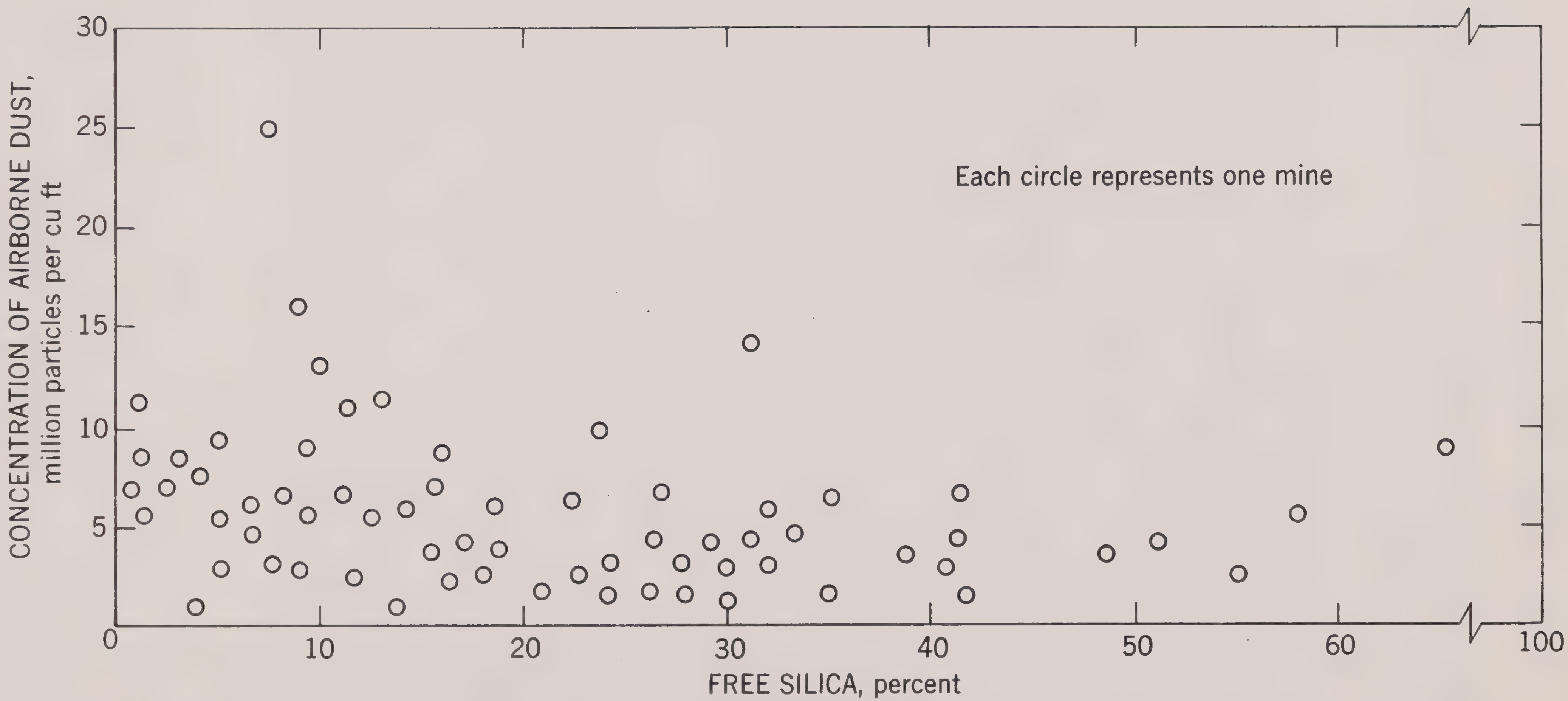


FIGURE IV.5.—Average of midget impinger samples collected in each mine in respect to dust concentration and free silica content.

CONCENTRATION OF AIRBORNE DUST, million particles per cu ft	FREE SILICA, percent 0–10	10–20	20–30	30–40	40–50	50–60	60–100
+50	90	34	12	49		2	1
45–50	12	14	3	2	2		
40–45	23	9	5	10			
35–40	37	16	11	9		1	
30–35	42	17	4	21	1	1	
25–30	65	20	17	25	3	1	1
20–25	95	65	25	25	3	3	
15–20	140	111	60	35	9	2	
10–15	300	190	78	95	20	15	6
5–10	660	425	415	240	75	35	3
0–5	3,071	2,690	2,320	2,410	410	225	21

Total samples, 14,837
Samples containing excessive dust, 1,440
Percent containing excessive dust, 9.7

FIGURE IV.6.—Distribution of midget impinger samples collected in respect to dust concentration and free silica content.

TABLE IV.10.—*Occupational dust exposures, underground, weighted averages*

Occupation	Number of places	Number of samples	Weighted averages mppcf
Sublevel cave miners	111	1, 746	8. 5
Block cave miners	113	1, 725	7. 5
Room and pillar miners	103	1, 592	7. 1
Shrinkage stope miners	15	227	5. 4
Open stope miners	42	651	4. 4
Square set miners	138	2, 102	3. 3
Cut and fill miners	87	1, 322	3. 2
Top slice miners	6	97	2. 8
Transportation	123	1, 767	5. 2
Maintenance and construction	20	305	13. 8
Other	31	392	4. 0

Man Trips.—Four percent of the midget impinger samples collected during operation of man trips contained excessive concentrations of dust. These high concentrations were caused by recirculation of air, dusty equipment, and dry roadways.

Slushing.—Eighteen percent of all samples collected during slushing operations contained excessive concentrations of dust. This was due principally to inadequate ventilation, recirculation of air, and lack of sufficient water before and during slushing operations. This is one of the principal sources of dust in mining, and rigid control methods are essential if the general levels of dust concentrations throughout the mine are to be reduced to any appreciable extent.

Mucking.—Fourteen percent of all midget impinger samples collected during machine and hand mucking contained excessive concentrations of dust. These high concentrations were usually the result of inadequate ventilation, recirculation of air, lack of sufficient water before and during mucking operations, and excessive use of blowpipes.

Timbering.—Only 3 percent of the samples collected during timbering contained excessive concentrations of dust, and in most cases contaminated air from other sources was a contributing factor. During removal of old timbers, dislodgment of settled dust sometimes created a problem.

Drilling and Loading Holes.—Approximately 11 percent of the samples collected during these operations contained excessive concentrations of dust. In addition to improper ventilation, collaring of holes dry, inadequate use of water, and defective equipment were the principal deficiencies noted. One sample, collected while a drill was operated dry for 3 minutes, contained 460 mppcf. Use of blowpipes, coupled with substandard ventilation, created excessive

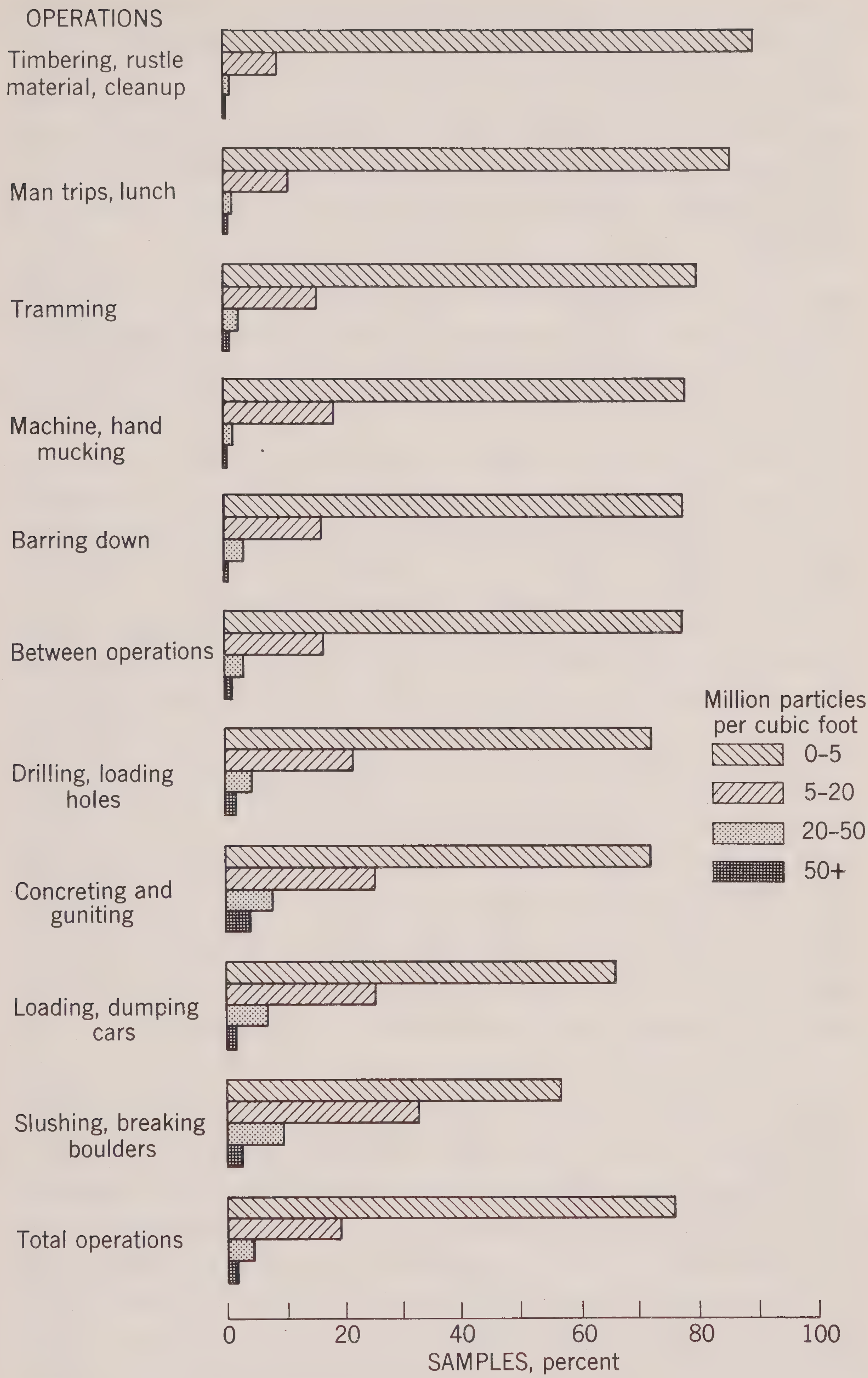


FIGURE IV–7.—Ranges and percentages of dust concentrations underground.

concentrations of dust while blowing out holes, which usually was an operation of short duration performed on the average of once each shift.

Tramming.—Nine percent of the samples collected during tramming operations contained excessive concentrations of dust. This was due to improper ventilation, including recirculation of air, inadequate maintenance of roadways, and inadequate maintenance of equipment.

Loading and Dumping Cars.—In these operations 15 percent of the samples contained excessive concentrations of dust. Improper ventilation, lack of sufficient water to wet the muck thoroughly, and excessive use of blowpipes, both to free muck in the chutes and to loosen the ore in the cars at the dumping points, were the principal factors involved.

Skip Tenders.—Skip tenders were exposed about 19 percent of the time to excessive dust concentrations. These concentrations were due usually to the same factors that were influencing the loading and dumping operations. In addition, the muck was often much drier, due to increased exposure to the ventilating currents.

Between Operations.—Approximately 1,450 of the midget impinger samples collected underground were taken during waiting periods. Men would be waiting for smoke to clear after blasting, for supplies, repairs to equipment, or in many cases, for another train of empty cars before resuming slushing or mucking operations. Seven percent of these samples contained excessive concentrations of dust. In most instances, the dust was created by other operations and was carried to the men by the ventilating current. Men were inclined to wait near the scene of operations, rather than retreat to a relatively dust-free area. This was especially noticeable where men were waiting for fumes and dust to clear following a blast. In some cases, where several stopes were ventilated by one continuous current of air, dust from one stope would be carried considerable distances to men who were waiting downwind.

Eating Lunch.—Approximately 5 percent of the midget impinger samples collected while men were eating lunch contained excessive concentrations of dust. In some instances men ate in or close to the working area and were subjected to residual dust in the air, or to dust being carried in the ventilating current from another source. Men frequently entered heated lunchrooms, and when their damp clothing began to dry, considerable dust would be liberated in the lunchroom in which there was no positive circulation of air. Loose plank flooring in lunchrooms was another source of dust. When this condition was pointed out to one company, the plank floors were replaced with floors consisting of 2 by 4's placed on edge, and spaced about one-half inch apart. These floors were then washed twice daily.

Concrete and Gunite Crews.—About 15 percent of the dust concentrations determined in connection with concreting and guniting operations were excessive. Concentrations in excess of 100 mppcf while concreting and in excess of 500 mppcf while guniting, were obtained. Handling of dry materials, and such practices as loosening sand and cement by beating on the sides of metal mine cars with hammers, contributed to these high concentrations. Approximately 25 percent of the employees engaged in this work wore approved respirators.

Rock Bolting.—About 12 percent of the samples collected during rock-bolting operations contained excessive concentrations, and in most cases, these were the result of inadequate ventilation. Water was used throughout all drilling operations for rock bolting.

Mobile Equipment Operators.—These operators were exposed to excessive concentrations of dust in 15 percent of the cases. Most of this was the result of crawler-mounted equipment slipping on hard bottom, poorly maintained roadways, and inadequate ventilation.

Barring Down.—Seven percent of the samples collected during barring down operations contained high concentrations. Much of this was due to a buildup of dust due to inadequate ventilation. Often the ventilating current was insufficient to remove dust from previous operations, such as blasting, especially when the workmen returned to the area very shortly after blasting.

Breaking Boulders.—Fifteen percent of the midget impinger samples collected while breaking boulders contained excessive concentrations of dust. These boulders were broken usually by one of two methods: secondary blasting, which required the drilling of short holes, or by use of sledgehammers. Many of these short holes were drilled dry, and excessive concentrations of dust were generated. Boulders being broken with sledges were often coated with dry dust which was dispersed as the boulders were broken. On several occasions, recirculated air from another operation added to the dust load.

When excessive dust concentrations were present, improper ventilation was often a contributing factor. Lack of sufficient air movement would result in a buildup in dust concentrations, even in such locations as lunchrooms. Air that was recirculated from another dust-producing operation often added to the general dust load. Some examples follow: (a) Employees walking along a haulageway were exposed to concentrations of 24 mppcf. This was due to dust from other operations being carried along the haulways by the ventilating current. (b) Men barring down in a raise were exposed to air containing 40 mppcf. There was no perceptible movement of air, and a buildup of dust was evident. (c) During slushing operations in a drift in which there was no perceptible movement of

air, concentrations of 70 mppcf were measured. (d) During another slushing operation, 6,000 cfm of air was passing the slusher operator. This air was being recirculated from another area and contained 37 mppcf of dust.

It was evident that merely introducing large volumes of air into a mine was not sufficient to assist materially in reducing dust concentrations in the working areas. To derive full benefit from all air entering a mine, it is essential that the secondary air currents be properly controlled. Recirculation must be avoided as much as practicable, and each working area must be supplied with clean air delivered at sufficient velocity to sweep the area, and in sufficient volume to dilute dust concentrations to acceptable levels.

Mills and Crushers

A total of 1,683 midget impinger samples was collected in the mills and crushers, 1,258 on the surface and the remainder underground. Of this number, 13 percent contained excessive concentrations of dust. Table IV.11 is a summary of the samples, and figure IV.8 shows the distribution of the samples in the various ranges of concentration and free silica content.

TABLE IV.11.—*Midget impinger samples collected at surface and underground mills and crushers*

Location	Number of samples	Samples containing excessive concentrations of dust	
		Number	Percent
Total	1, 683	219	13. 0
Mills	1, 145	108	9. 4
Crushers	459	98	21. 4
Assayers in mills	79	13	16. 5

Mills.—Slightly over 9 percent of the midget impinger samples collected in the mills contained excessive concentrations of dust. Many of these high concentrations occurred during cleanup operations, such as sweeping dry floors and using compressed air to remove accumulations of dust. Spillage from conveyors was another factor; also the lack of suitable dust control measures at transfer points along the conveyor lines.

Crushers.—About 21 percent of the midget impinger samples collected in the crusher areas contained excessive concentrations of

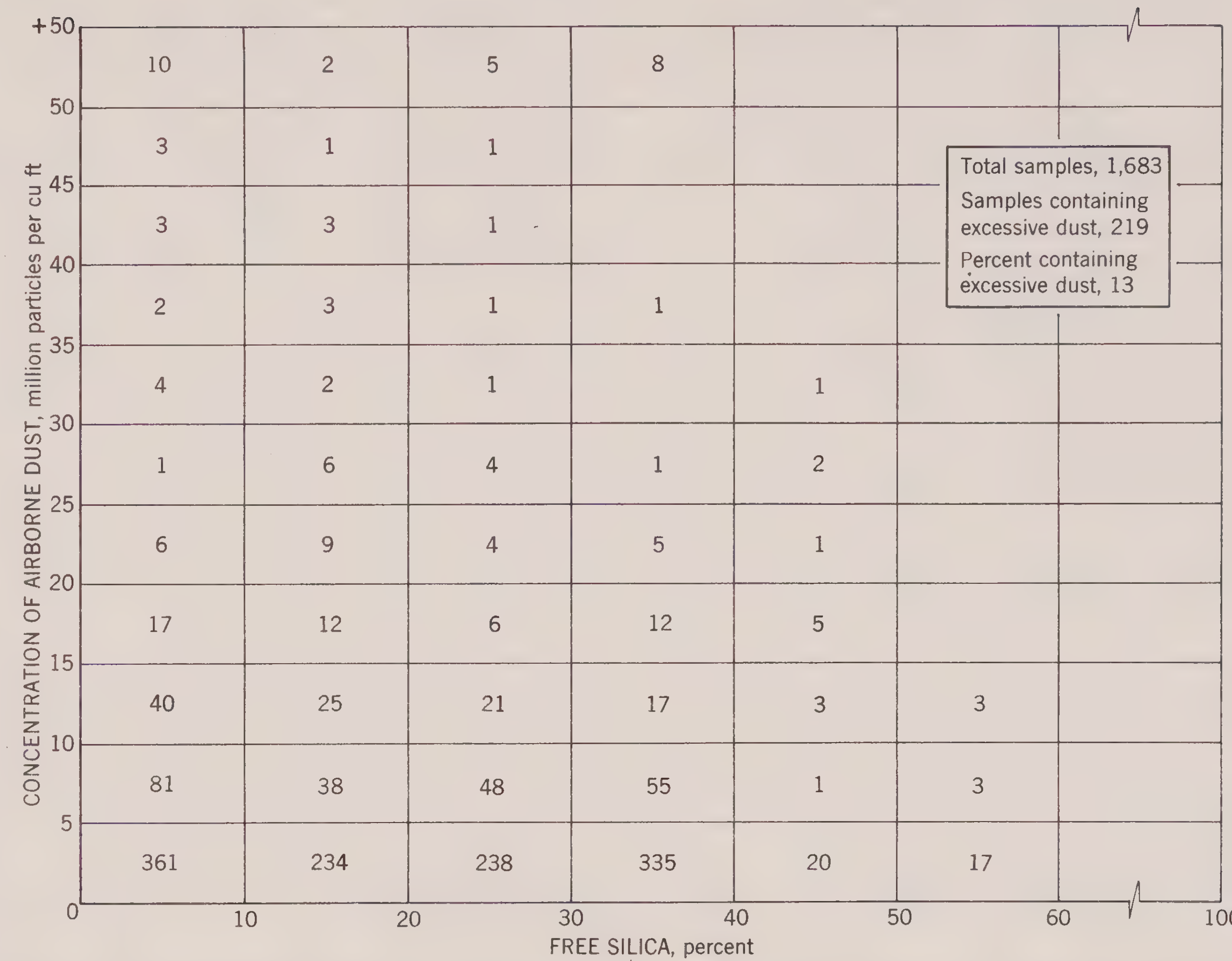


FIGURE IV.8.—Distribution of midget impinger samples collected in mill and crusher locations in respect to dust concentration and free silica content.

dust. Crushing is inherently a dusty operation, and extreme care is essential to prevent the dust from becoming airborne. Improper maintenance of equipment, resulting in leakage around joints, and poor cleanup practices, were evident in many cases. Lack of dust collecting systems and lack of effective ventilation in the buildings were contributing factors.

Assayers in Mills.—Assayers, when collecting samples, were frequently subjected to the same concentrations of dust as other employees working in the mills and around crusher operations. In many instances, the assay laboratory was located in the mill. Laboratory procedures included the pulverizing of ore samples, and high concentrations of dust resulted when exhaust ventilation systems were inadequate or nonexistent. The use of airhose by the assayer when cleaning up equipment also was a contributing factor. The pulverizing operations usually were of short duration, and in 25 percent of the cases, the assayer wore a Bureau of Mines approved respirator. Sixteen percent of the midget impinger samples collected while assayers were working around mills, and in laboratories located in mill buildings, contained excessive concentrations of dust.

Shops and Other Surface Locations

A total of 1,660 midget impinger samples was collected in the shops, hoistrooms, and other surface locations. Of this number, only 6.7 percent contained excessive concentrations of dust. Table IV.12 is a summary of the samples, and figure IV.9 shows the distribution in the various ranges of concentration and free silica content.

TABLE IV.12.—*Midget impinger samples collected at surface locations*

Location or operation	Number of samples	Samples containing excessive concentrations of dust	
		Number	Percent
Total	1, 660	112	6. 7
Shops	1, 032	73	7. 1
Toplanders and hoistmen	231	0	0
Assay laboratories	117	22	18. 8
Dumpmen	75	0	0
Bullgangs and pumpers	62	0	0
Concentrate loaders	50	14	28. 0
Shovel, compressor, crane, and truck operators	66	0	0
Concrete plants	18	3	16. 7
Sand blasters	9	0	0

CONCENTRATION OF AIRBORNE DUST, million particles per cu ft	FREE SILICA, percent: 0–10	10–20	20–30	30–40	40–50	50–60	60–100
50 to +50	7	1	4	11		1	
45–50			2				
40–45	1		1	5		2	
35–40	1	2		2			
30–35	3	1	2	3			
25–30	3	4		1			
20–25	6	3	2	1			
15–20	2	2	1	7	3		
10–15	19	5	7	3			
5–10	30	28	13	24		2	
0–5	364	404	281	326	44	18	8

Total samples, 1,660
Samples containing excessive dust, 112
Percent containing excessive dust, 6.7

FIGURE IV.9.—Distribution of midget impinger samples collected in shops and surface locations in respect to dust concentration and free silica content.

Shops.—In the shops, 7 percent of the 1,032 midget impinger samples collected contained high concentrations of dust. Lack of exhaust ventilation was apparent in many locations. Sweeping up dry materials was another factor. The practice of cleaning off machinery by use of compressed air often contributed to the dustiness of the atmosphere.

Assay Laboratories.—Assayers sampled in this category included only those working in laboratories which were not located in the mills. About 19 percent of the samples collected in these laboratories contained excessive concentrations of dust. Pulverizing of ore for assaying created considerable dust, and the use of airhose to clean up equipment tended to keep the dust suspended for some time. In 25 percent of the cases, the assayer wore a Bureau of Mines approved respirator while operating the pulverizing equipment.

Concentrate Loaders.—These employees were engaged in loading the concentrates for shipment, either by truck or by rail. The concentrate was usually dry, and caution was required to prevent dissemination of dust into the atmosphere. Of the 50 midget impinger samples collected, 28 percent contained excessive concentrations of dust. As this usually was a part-time operation, the use of approved respirators might offer at least a partial solution.

Concrete Plants.—Few men were employed in concrete plants. Their function was to premix concrete for underground use. Of the 18 midget impinger samples collected in concrete plants, 3 contained excessive concentrations of dust.

Other Operations.—A total of 443 midget impinger samples was collected at various surface locations and during various operations. There was some question as to the efficiency of air-supplied helmets during sandblasting operations. Nine samples collected inside the helmets contained very low concentrations of dust. Two hundred and thirty-one midget impinger samples were collected in hoistrooms and around the shaft collars while toplanders were performing their normal duties. None of these samples contained excessive concentrations of dust. None of the 75 midget impinger samples collected while dumpmen were working on the surface contained excessive concentrations of dust.

One hundred and twenty-eight midget impinger samples were collected where equipment operators, pumpers, and general laborers were working. None of these samples contained excessive concentrations of dust.

Table IV.13 is a summary of occupational classifications for which arithmetic averages, rather than weighted averages, were calculated, as dust concentrations in operations of this type remained fairly constant over a full shift.

TABLE IV.13.—*Occupational dust exposures, surface and underground, arithmetic averages*

Location or occupation	Number of samples in each category	Range of dust concentrations, mppcf							
		0–5		5–20		20–50		Over 50	
		Number	Percent	Number	Percent	Number	Percent	Number	Percent
	Surface								
Total	1, 660	1, 445	87. 0	146	8. 8	45	2. 7	24	1. 5
Shops	1, 032	904	87. 7	93	9. 0	20	1. 9	15	1. 4
Toplanders and hoistmen	231	231	100. 0	0	0	0	0	0	0
Assay laboratories	117	87	74. 4	17	14. 5	8	6. 8	5	4. 3
Mobile equipment operators	66	54	81. 8	7	10. 6	3	4. 6	2	3. 0
Dumpmen	75	56	74. 7	15	20. 0	4	5. 3	0	0
Concentrate loaders	50	33	66. 0	9	18. 0	6	12. 0	2	4. 0
Miscellaneous	89	80	89. 9	5	5. 6	4	4. 5	0	0
	Underground								
Total	1, 362	1, 039	76. 3	246	18. 1	51	3. 7	26	1. 9
Mechanics, nippers, electricians, pumpers	414	352	85. 0	58	14. 0	2	. 5	2	. 5
Skiptenders	310	168	54. 2	104	33. 6	32	10. 3	6	1. 9
Concrete and gunite crews (weighted averages)	200	144	72. 0	34	17. 0	7	3. 5	15	7. 5
Hoistmen and cagers	160	150	93. 8	9	5. 6	1	. 6	0	0
Track crews	131	121	92. 4	7	5. 3	2	1. 5	1	. 8
Diamond drillers	118	88	74. 6	24	20. 3	6	5. 1	0	0
Samplers	29	16	55. 2	10	34. 5	1	3. 4	2	6. 9
	Surface and underground								
Total	1, 683	1, 205	71. 6	387	23. 0	66	3. 9	25	1. 5
Mills	1, 145	939	82. 0	179	15. 6	18	1. 6	9	. 8
Crushers	459	230	50. 1	179	39. 0	40	8. 7	10	2. 2
Assayers in mills	79	36	45. 6	29	36. 7	8	10. 1	6	7. 6

TABLE IV. 14.—*Dust concentrations in underground operations*

Operation	Total samples each operation	0–5 mppcf		5–20 mppcf		20–50 mppcf		Over 50 mppcf	
		Number	Percent	Number	Percent	Number	Percent	Number	Percent
Total	14, 480	10, 952	75. 6	2, 798	19. 3	558	3. 9	172	1. 2
Timbering	1, 149	1, 036	90. 2	99	8. 6	10	. 9	4	. 3
Rustle material	338	302	89. 3	33	9. 8	2	. 6	1	. 3
Clean up	40	35	87. 5	5	12. 5	0	0	0	0
Man trips	1, 385	1, 192	86. 0	163	11. 8	23	1. 7	7	. 5
Lunch	692	596	86. 1	74	10. 7	15	2. 2	7	1. 0
Tramming	964	767	79. 6	160	16. 6	33	3. 4	4	. 4
Hand mucking	645	514	79. 7	109	16. 9	16	2. 5	6	. 9
Barring down	637	506	79. 5	107	16. 8	20	3. 1	4	. 6
Waiting (all operations)	1, 832	1, 441	78. 7	317	17. 3	57	3. 1	17	. 9
Machine mucking	550	425	77. 3	120	21. 8	2	. 4	3	. 5
Drilling	2, 566	1, 852	72. 1	564	22. 0	104	4. 1	46	1. 8
Loading holes	718	513	71. 5	158	22. 0	36	5. 0	11	1. 5
Dumping cars	442	305	69. 0	102	23. 1	30	6. 8	5	1. 1
Loading cars	577	370	64. 2	156	27. 0	41	7. 1	10	1. 7
Breaking	226	134	59. 3	72	31. 8	14	6. 2	6	2. 7
Slushing	1, 719	964	56. 1	559	32. 5	155	9. 0	41	2. 4

Table IV.14 is a summary of all midget impinger samples used to determine full shift weighted average exposures of underground employees performing various operations. The total number of midget impinger samples listed in this table exceeds the number actually collected for this purpose by approximately 10 percent, as numerous samples were used to determine exposures during two or more operations. For example, during the period in which a sample was collected, a haulage crew might load, tram, and dump cars. This sample would be used to indicate exposures during each operation, and thus would be recorded three times in table IV.14.

The number of places sampled, number of samples taken, and the high sample and average dust concentrations are shown in groupings as to locations both surface and underground in table IV.15. In all locations, the lowest concentration sampled contained less than 1 million particles of dust per cubic foot of air.

TABLE IV.15.—*Occupational dust exposures, surface and underground*

Locations	Number of places	Number of samples	High sample (mppcf)	Average (mppcf)
SURFACE				
Shops:				
Machinist—mechanic	74	269	20	2
Blacksmith	42	176	50	3
Welder	43	152	390	18
Bit sharpener	14	60	130	7
Drill doctor	16	57	10	2
Electrician	34	108	20	2
Carpenter	35	127	25	1
Sandblaster	3	9	4	2
Concrete batch plant operator	6	18	40	10
Sweeper	3	6	30	5
Garage	15	50	5	1
Tinsmith	6	17	6	2
Saw filer	6	16	5	1
Surface mine service:				
Toplander	22	65	3	1
Hoistman	54	166	3	1
Power shovel operator	3	10	2	1
Truck driver	3	10	6	3
Crane operator	5	20	60	5
Compressor operator	9	26	5	1
Crusher (surface and underground):				
Dumpman	20	75	25	3
Primary crusher operator	48	175	60	9
Secondary crusher operator	21	75	110	10
Conveyor belt operator	57	192	530	11
Woodpicker	15	52	55	6

TABLE IV.15.—*Occupational dust exposures, surface and underground*—Continued

Locations	Number of places	Number of samples	High sample (mppcf)	Average (mppcf)
SURFACE—continued				
Crusher (surface and underground)—Continued				
Fine ore storage	38	122	70	6
Shaker screen or grizzly operator	24	79	45	8
Sweeper or cleanup man	3	13	270	30
Mill (surface and underground):				
Grinding	47	179	13	2
Flotation operator	32	117	12	2
Shaker table operator	10	38	8	2
Thickener and filter operator	17	65	125	4
Kiln operator	11	36	15	2
Concentrate loader	16	50	340	14
Pumpman	13	42	6	2
Bull gang	4	12	20	3
Reagent mixing	14	52	450	25
Assay office	47	196	120	13
Hoisting (surface and underground):				
Underground hoistman	31	94	40	2
Skiptender	47	310	100	9
Cager	19	76	11	2
UNDERGROUND				
Haulage and dumps:				
Conveyor belt operator	5	43	20	5
Grizzlyman	27	140	170	9
Chute puller	13	106	130	11
Dispatcher	6	18	20	4
Mine maintenance:				
Bulldozer operator	3	17	60	14
Timber repairman	43	385	170	6
Ventilation crew	3	30	12	2
Track crew	22	101	70	3
Mechanic	58	224	50	4
Electrician	13	44	30	4
Drill doctor	8	24	12	2
Pumpman	13	55	7	1
Nipper	10	67	11	2
Exploration:				
Sampler	7	29	55	16
Diamond driller	20	118	25	2

TABLE IV.15.—*Occupational dust exposures, surface and underground*—Continued

Locations	Number of places	Number of samples	High sample (mppcf)	Average (mppcf)
UNDERGROUND—continued				
Open stopes:*				
Stope miner	16	244	45	3
Drift miner	3	42	20	3
Raise miner	2	28	130	10
Driller	14	225	40	4
Trackless loader operator	5	79	12	3
Draw-point mucker operator	2	33	370	17
Room-and-pillar stopes:*				
Stope miner	25	393	145	3
Drift miner	8	129	170	8
Stope driller	40	602	520	8
Trackless loader operator	15	236	90	9
Slusher	12	182	190	12
Powderman	3	50	25	7
Shrinkage stopes:*				
Stope miner	11	168	70	6
Drift miner	2	32	40	6
Scram drift slusher operator	2	27	7	4
Cut-and-fill stopes:*				
Stope miner	50	763	180	3
Drift miner	20	297	90	3
Raise miner	7	106	120	5
Stope filler	10	156	90	3
Square set stopes:*				
Stope miner	87	1, 337	100	3
Drift miner	22	340	50	3
Raise miner	17	241	40	4
Slusher operator	4	58	40	2
Stope filler	8	126	570	10
Block cave stopes:*				
Stope miner (chute tapper)	56	852	700	8
Undercut miner	5	76	60	4
Drift miner	35	538	50	3
Raise miner	17	259	370	10
Sublevel cave stopes:*				
Stope miner	49	770	175	6
Drift miner	29	455	200	6
Raise miner	6	101	170	6
Longhole driller	6	94	320	30
Slusher operator	20	311	120	11
Stope filler	1	15	20	10
Top-slice stopes:*				
Stope miner	6	97	24	3

See footnote at end of table.

TABLE IV.15.—*Occupational dust exposures, surface and underground*—Continued

Locations	Number of places	Number of samples	High sample (mppcf)	Average (mppcf)
UNDERGROUND—continued				
Transportation:*				
Locomotive crew	102	1,509	340	5
Truckdriver	3	66	45	4
Shuttle car operator	15	170	20	5
Hand trammer	3	22	12	3
Maintenance and construction:*				
Concrete crew	15	229	170	7
Gunite crew	2	30	670	80
Motor grader operator	3	46	16	3
Miscellaneous:*				
Shaft, station, winze, and sump miner	26	317	55	3
Rock bolter	5	75	100	9

*The averages shown for these occupational groups are weighted averages. All others are arithmetic averages.

Dust Control

Dust control and dust evaluation programs were in effect at 40 mines. The ventilation, safety, or industrial hygiene departments were usually responsible for these programs. Continuous dust monitoring was routine at many of these mines, and a spot-sampling method was used at the remaining mines in this group. These programs permit detection of sources of high dust concentrations and institution of proper control measures. Most of the usual dust control measures, such as application of water, adequate ventilation, and use of dust collecting devices, were well known to the industry. In most cases, when substandard conditions were found by personnel conducting this study, they had resulted from failure to recognize or apply these well known principles. Table IV.16 lists some of the effective measures used to reduce dust exposures.

TABLE IV.16.—*Measures to reduce dust exposures*

Underground:

1. Sufficient primary ventilation.
2. Auxiliary fans and tubing for secondary ventilation.
3. Wet drilling.
4. Wetting down of muck piles, before and during slushing.
5. Air-water blasts.
6. Water sprays at grizzlies, loading, transfer and dumping points, in intake and return airways, and along haulageways.

TABLE IV.16.—*Measures to reduce dust exposures*—Continued

Underground—Continued

7. Wetting down of surface areas around air intakes.
8. Off-shift or end-of-shift blasting.
9. Hydraulic filling in preference to dry filling.
10. Location of employee with respect to dust generating operation.

Surface:

1. Exhaust fans and hoods.
2. Dust collectors.
3. Water sprays and hoses.
4. Enclosed or enclosed and pressurized cabs and booths.
5. Filtered air systems.
6. Supplied-air helmets.*
7. Roof ventilators.

Underground and surface:

1. Air conditioning.
2. Dust collectors.
3. Good housekeeping practices.
4. Application of calcium chloride or oil on haulageways.
5. Dust respirators.*

*Not recommended for long intervals; to be used only when dust control measures are not practical.[19]

Some of the more common practices that produced high dust concentrations in working places are listed in table IV.17.

TABLE IV.17.—*Practices that caused dusty conditions*

1. Failure to make proper use of primary or secondary ventilation. In some cases recirculation of air resulted in blasting fumes and dust generated at one location being carried to employees working downwind.
2. Collaring of holes dry, or drilling with an insufficient volume of water.
3. Use of blowpipe to clean roadways, pockets, and to clear holes drilled for blasting.
4. Use of airhammer without dust control.
5. Poor housekeeping and cleanup practices.

VENTILATION

Ventilation is needed for the comfort and efficiency of mineworkers. Well directed ventilation is desirable in every underground working place to replenish oxygen and to remove or dilute harmful gases and dusts.[20, 21] To insure proper ventilation in each working place, it is essential that a sufficient volume of air be introduced into the mine, preferably by means of electrically operated fans. The air must be properly circulated so that fresh air is delivered to each working section. Some mechanical means of secondary ventilation is then usually necessary to assure that sufficient air of good quality is coursed to the individual working places.

The total volume of air entering each of 53 mechanically ventilated mines was measured. Data could not be obtained on five other mechanically ventilated mines because of numerous openings to the surface. Nine mines included in the study relied on natural draft for ventilation. Table IV.18 is a summary of ventilation rates at the 53 mines.

TABLE IV.18.—*Ventilation rates at 53 mines with mechanical ventilation*

Ventilation rates, cfm	Up to 20,000.	20,000–50,000	50,000–100,000	100,000–250,000	Over 250,000
Number of mines.	8	15	11	13	6

Table IV.19 lists methods of ventilation in working places in which midget impinger samples of airborne dust were collected.

TABLE IV.19.—*Methods of ventilation in underground working places*

Mining method	Number of places	In-line flow	Fan with or without tubing	Compressed air*	Convection or natural draft sufficient to measure	Air velocities insufficient to measure
Total	588	136	178	21	42	211
Percent of total	100	23	30	4	7	36
Topslice	9	0	4	0	0	5
Development	10	4	6	0	0	0
Shrinkage	12	5	2	0	0	5
Open stopes	39	5	2	5	8	19
Cut and fill stopes	58	14	29	0	2	13
Sublevel cave	104	14	33	3	14	40
Block cave	116	23	27	9	7	50
Room and pillar	56	9	17	0	6	24
Square set	184	62	58	4	5	55

*Air operated fans, and compressed air used only for ventilation. Does not include exhaust air from drills and other air-operated equipment.

Composition of Mine Atmospheres

Samples of mine atmosphere were collected at each mine for determination of air quality. Such samples were collected only in situations where the quality of the air might be suspect, and did not reflect average conditions in the mine. For example, samples were collected in locations where men returned to the working place

Compressed air and water mist spray used during blasting cycle in headings. (Courtesy of The Anaconda Co., 1963.)

shortly after blasting. Samples were collected in all mines where diesel equipment was operating, and in the main returns at each mine. Management was notified in all instances when analyses indicated contaminants in the mine atmosphere in excess of suggested limits. Table IV.20 is a summary of all air samples collected under these conditions.

Mine air is considered to be of good quality when it contains at least 19.5 percent oxygen, and not more than 0.5 percent carbon di-

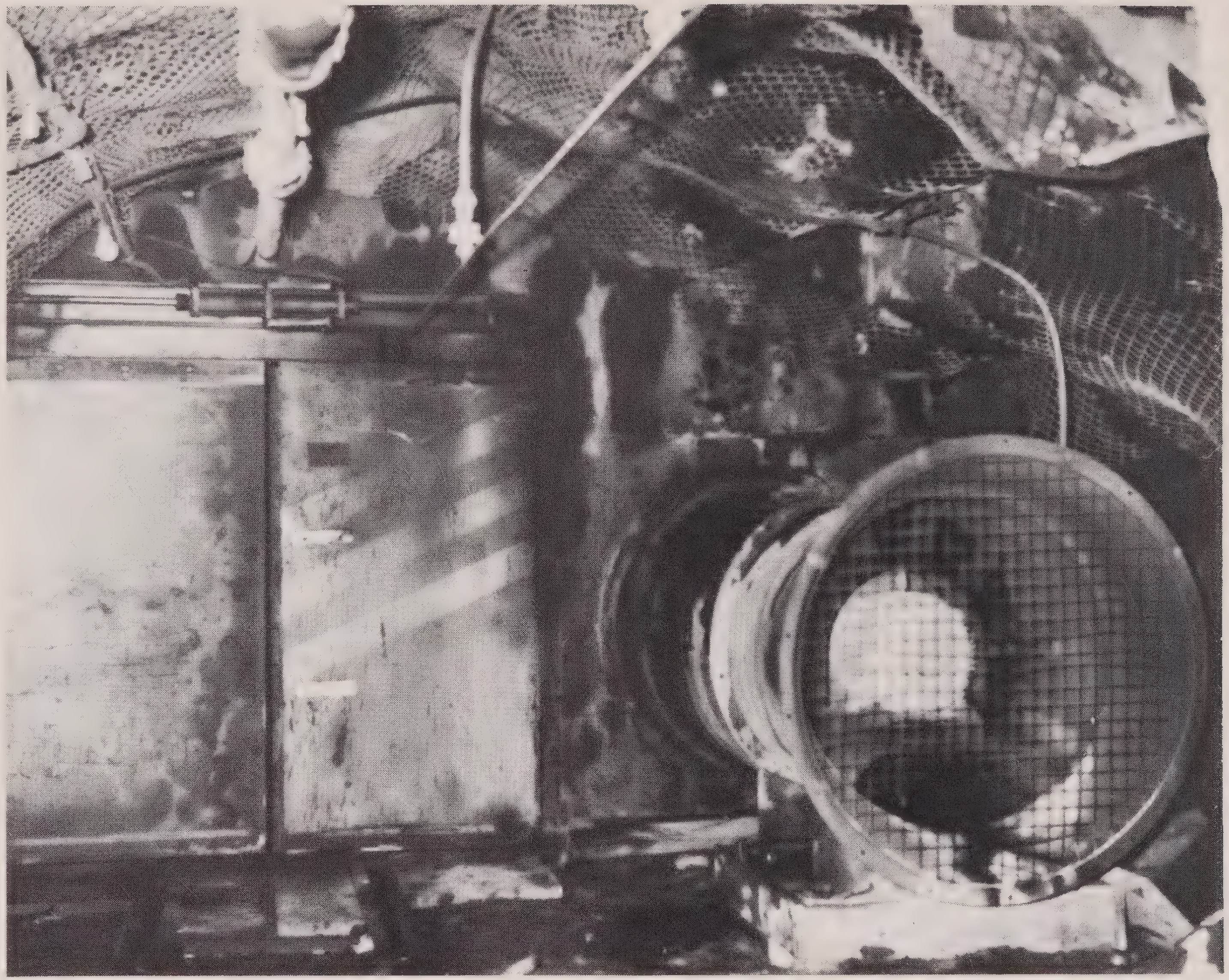
oxide, 0.01 percent carbon monoxide, or 5 parts per million of nitrogen dioxide. As field instruments specific for detection of nitrogen dioxide were not available when the study began, the air samples were analyzed for total oxides of nitrogen (except nitrous oxide), for which the suggested limit was 25 parts per million.[22]

As shown in table IV.20, 2 percent of the air samples collected contained carbon dioxide in excess of the suggested limit, 5 percent exceeded the suggested limit for carbon monoxide, and 4 percent exceeded the suggested limit for oxides of nitrogen. All samples collected contained at least 20 percent oxygen.

TABLE IV.20.—*Composition of mine atmospheres*

Constituent	Range of concentration	Number of samples	Percent of total	Cumulative percent
	Percent by volume			
Carbon dioxide	Total	307		
	0.03–0.10	153	50	50
	0.11–0.20	91	30	80
	0.21–0.30	28	9	89
	0.31–0.40	23	7	96
	0.41–0.50	6	2	98
	Over 0.50	6	2	100
	Percent by volume			
Carbon monoxide.	Total	300		
	None detectable	203	68	68
	Less than 0.0025	21	7	75
	Not over 0.005	26	9	84
	0.005–0.01	33	11	95
	Over 0.01	17	5	100
	Parts per million			
Oxides of nitrogen.*	Total	276		
	0	158	57	57
	0–5	39	14	71
	6–10	36	13	84
	11–15	19	7	91
	16–20	9	3	94
	21–25	5	2	96
	Over 25	10	4	100
	Percent by volume			
Oxygen	None under 20.			

*Total oxides of nitrogen, except nitrous oxide, N_2O. Portable instruments specific for determination of nitrogen dioxide not available for field use at time of study.



Airlock door and fan on main adit. (Courtesy of Union Carbide Nuclear Co., 1963.)

Conclusions on Dust Production and Control

The foregoing discussion of observed conditions in underground and surface operations leads to the following conclusions:

1. The effective use of the ventilating currents in the working areas was indicated as a problem which needed immediate attention.
2. Water applied to the muck piles will assist materially in reducing dust concentrations during subsequent operations.
3. Drilling, slushing, and crusher operations were the most prolific dust-producing operations to which men were directly exposed.
4. Dust concentrations in shops, except during cleanup operations, presented no particular problems.
5. Better maintenance, cleanup procedures, and dust control measures were indicated around crusher installations and concentrate loading.
6. It was noted, incidentally, that ventilation often was inadequate during welding operations.

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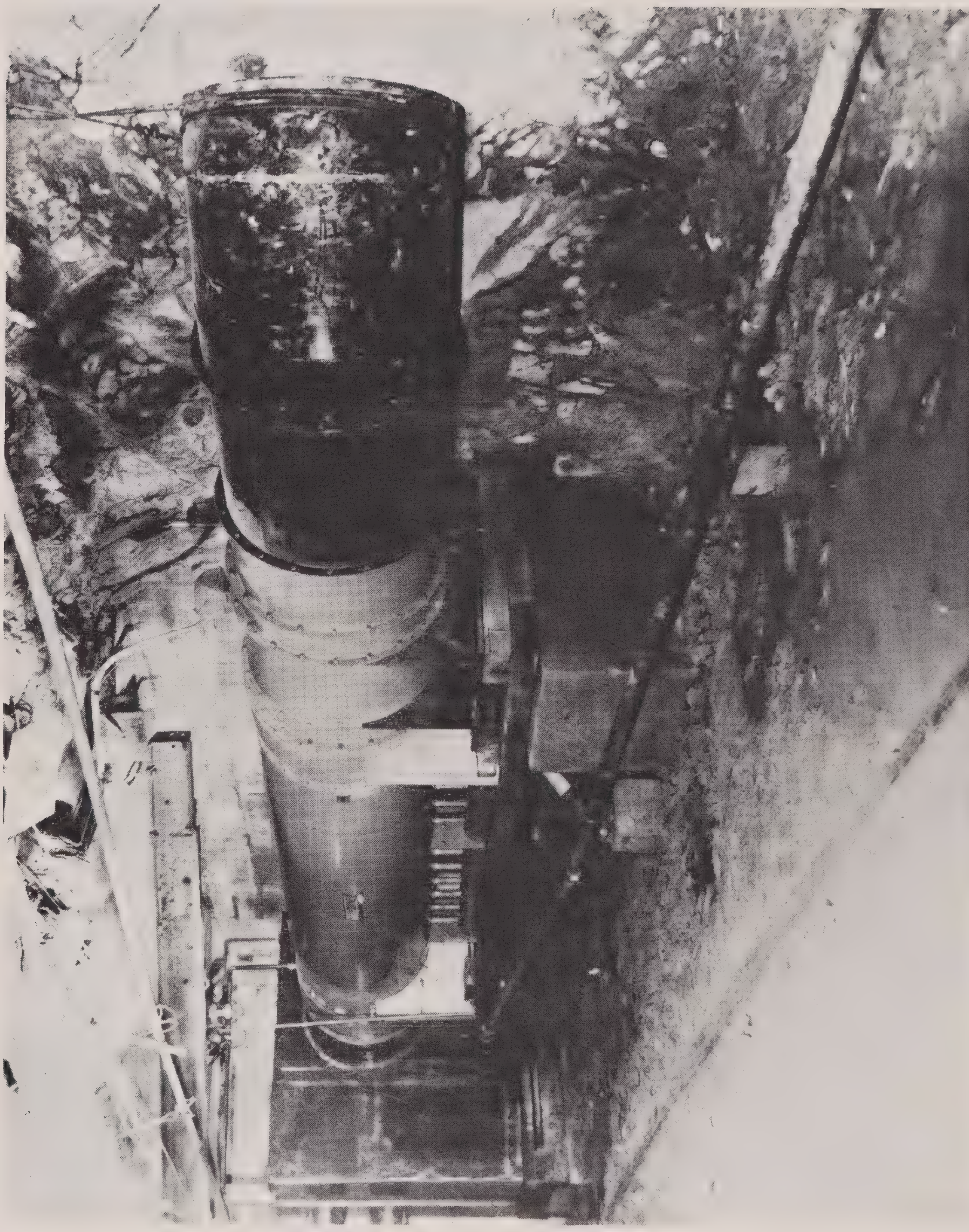
Part B—History of Dust Sampling and Comparison of Methods

Since the development in 1886 of the sugar tube for the collection of airborne bacteria and its subsequent application in the collection of airborne dust, various methods for the evaluation of man's exposures in dusty industrial environments have been suggested, and improvements in methods of collection and measurement of particulate matter have been made. During this period several methods of evaluation developed in the United States, Great Britain, Germany, and other parts of the world have gained some measure of acceptance and use. Table IV.21 lists in chronological order some of these major developments.

Although research in the United States has continued on other methods of evaluation, since the early 1920's investigators in this country have almost exclusively utilized standard or midget impingers for sample collection, and light-field microscopy for counting, in the measurement of exposures to pneumoconiosis-producing min-



Underground dust collector. (Courtesy of The Anaconda Co., 1963.)

TABLE IV.21.—*Methods for determination of dust in air*

APPROXIMATE CHRONOLOGICAL RECORD OF DEVELOPMENT OF SOME OF THE METHODS USED FOR DETERMINING DUST IN AIR

Approximate dates	Bureau of Mines	U.S. Public Health Service	Others	England	South Africa
Before 1870	Amount of dust in air usually estimated visually.				
1886				Sugar tube described by Frankland for use in sampling bacteria in air.[1]	
1888				Aitken described his dust counter later much used for determining particulate matter in ordinary air.[2]	
1902–1903				Dust collected from air of Cornish mines by filtration through cotton wool and determined by weighing.[3]	Dust collected from air of mines by filtration through sugar tube and determined by weighing.[4]
1905–1907			Sugar tube used in determining dust in air of subways of New York City.[5]		

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TABLE IV.21.—*Methods for determination of dust in air*—Continued

APPROXIMATE CHRONOLOGICAL RECORD OF DEVELOPMENT OF SOME OF THE METHODS USED FOR DETERMINING DUST IN AIR—continued

Approximate dates	Bureau of Mines	U.S. Public Health Service	Others	England	South Africa
1908	----------	----------	Use of the method for counting organisms in water for counting dust in the liquid from sugar-tube samples described.[6]	----------	----------
1909	----------	----------	The American Public Health Association recommended use of sugar tube for collecting samples of dust from air "heavily laden with dust" and determination of collected dust by weight or count of number of particles.[7]	----------	----------
1911	----------	----------	Use of paper thimble for collecting dust from blast-furnace gas described.[8]	----------	Extensive use of sugar tube method for determining dust in air of mines began. Dust weighed.[4]

1912					Sugar tube adopted by Miners' Phthisis Prevention Committee.[4]
1913			Method for determining dust in air by causing dust to impinge against an adhesive surface in a Petri dish and counting dust described by Graham Rogers. This method accepted by American Public Health Association.[9]		Largest dust particles in ash of silicotic lungs were found to be about 12 microns in diameter.[4]
1914	Determined dust in air of mines of the Joplin District by collecting dust from air by sugar tube and weighing collected dust.[10]				
1915					Liquid suspension from sugar-tube samples filtered through 300-mesh screen to remove large particles.[4]
1916			Palmer apparatus described. Dust to be weighed or counted.[11]		Kotze konimeter described. Dust counted.[4]
1917			Palmer apparatus method recommended by American Public Health Association. Dust to be counted.[12]		

TABLE IV.21.—*Methods for determination of dust in air*—Continued

APPROXIMATE CHRONOLOGICAL RECORD OF DEVELOPMENT OF SOME OF THE METHODS USED FOR DETERMINING DUST IN AIR—continued

Approximate dates	Bureau of Mines	U.S. Public Health Service	Others	England	South Africa
1919	Counting of dust particles started.[15]	Palmer apparatus used in studies in potteries. Dust counted and weighed.[14]	Small electric precipitator described by Bill.[15]	----------	----------
1920	Method of counting and weighing dust above and below 10 microns in sugar-tube samples described.[16]	----------	----------	----------	----------
1922	Comparative study of the sugar tube, Palmer apparatus, Kotze konimeter, paper thimble, and Anderson-Armspach dust determinator was made at the Bureau of Mines, Pittsburgh Station, by the Bureau of Mines, Bureau of Chemistry, American Society of Heating and Ventilating Engineers' Research Laboratory, and the Public Health Service.[17] Greenburg-Smith impinger was developed during this study and included in the later part of the study.[19]			Owens jet dust counter described. Dust counted.[18]	----------
1923	Siliceous dust in water over 24 hours found to be somewhat soluble. Use of alcohol instead of water suggested for such dusts.[20]	Impinger method used in studies of health of workers in dusty trades. Dust counted and weighed. Cells allowed to settle 30 minutes. Konimeter also used in low-dust concentrations.[21]	Alternating-current precipitator described.[22]	----------	Acid vapor treatment of konimeter, slides started. Dark-field counts of konimeter samples started.[4]

1925	—	—	Determined dustiness by settlement.[23]	—	—
1929	—	—	—	—	Flugge-de-Smidt-Zeiss konimeter described.[24]
1932	The practice of separating dust into +10 micron fractions and of weighing dust in impinger samples discontinued.[13]	Impinger method as used by Public Health Service described.[25]	Modified form of the Greenburg-Smith impinger described by Hatch et al.[26]	Thermal precipitator described.[27]	
1934	—	—	Hatch cell described.[28]	—	—
1937	Midget impinger described.[29]	—	—	—	—
1938	Microprojection method for counting dust in impinger samples described.[30]	—	Barnes-Penney electrostatic precipitator described.[31]	—	—
1939–1940	—	—	Prepared sedimentation specimens for use with electron microscope (German).[32] Dust-counting methods in which cells 0.1 mm. deep used described.[33 34]	—	—

TABLE IV.21.—*Methods for determination of dust in air*—Continued

APPROXIMATE CHRONOLOGICAL RECORD OF DEVELOPMENT OF SOME OF THE METHODS USED FOR DETERMINING DUST IN AIR—continued

Approximate date	Bureau of Mines	U.S. Public Health Service	Others	England	South Africa
1943	----------	----------	Described electrostatic precipitator especially developed for use with electron microscope (German).[36] Verification of theory of light scattering by particulate matter.[37]	Explored relationship of weight to count.[35]	----------
1944	Midget microprojector described.[38] Filter-paper method for obtaining results comparable to impinger results described.[39]	----------	----------	----------	----------
1945	Determined size distribution of particles by electron microscope.[40]	----------	The cascade impactor for sampling coarse aerosols described.[41]	----------	----------
1946	----------	----------	Described high volume air sampler for particulate matter.[42]	----------	----------

1947	---	---	Gucker described photoelectric device for measuring dust concentrations.[43]	Oscillating thermal precipitator described by Walton.[44] Application of electron microscopy to particle size.[45]	---
1948	---	---	Described two stage sampler simulating respiratory tract.[46]	---	---
1951	---	Described use of membrane filter in sanitary bacteriology.[47]	Use of membrane filter for dust sampling (Russian).[48]	---	---
1953	---	Combination of electron microscope and molecular filter for particulates described.[49]	---	---	---
1954	---	---	---	Theory of size classification by elutriation.[50]	---
1958	---	---	---	Discuss relationship between particle number, area, and weight concentration.[51]	---

TABLE IV.21.—*Methods for determination of dust in air*—Continued

APPROXIMATE CHRONOLOGICAL RECORD OF DEVFLOPMENT OF SOME OF THE METHODS USED FOR DETERMINING DUST IN AIR—continued

Approximate date	Bureau of Mines	U.S. Public Health Service	Others	England	South Africa
1959				Determine particle size by beta-back scattering.[52]	
1960			Describe two stage samplers to simulate upper and lower respiratory tract.[53]		
1962	A technique for counting and sizing dust samples with a microprojector described.[55]			Use of long running thermal precipitator and photoelectric densitometer for coal dusts.[54]	

eral dust. Threshold limit values used in this country for interpreting the hygienic significance of exposures to such dusts are based upon these techniques. As a consequence it is necessary, in studies of dust exposures, to obtain data by these methods to permit comparison with past experience and with the accepted standards.

Although the impinger sampling, light-field counting method as applied in the United States has in the past, and continues now, to serve well as a general index of exposure upon which dust control may be designed or assessed, it does not define all of the factors believed to be of physiological importance in exposures to pneumoconiosis producing dusts. No other method, or combination of methods, however, has been shown to define the long sought dust exposure—physiologic response relationship, nor is there complete agreement among investigators regarding the measurable parameters which will define this relationship. Knowledge regarding the exposure-response relationship can be furthered, however, by continued study and application of a variety of environmental assessment techniques both in the laboratory and the field.

Throughout the course of the 1958–61 dust exposure study the standard methods of impinger dust sampling and light-field microscopic counting were applied for the determination of atmospheric dust concentrations. Cellulose ester membrane filters were used for the collection of atmospheric dust samples for the determination of particle-size distributions by optical and electron microscopy. Dust samples obtained underground for free silica analysis were, for the most part, settled dust samples, although a limited number of high volume filter and electrostatic precipitator samples were obtained in mines where electric power was available in suitable locations for operation of the sampling equipment. At surface operations settled dust samples, and high volume filter and electrostatic precipitator samples of airborne dust, were obtained for free silica analysis. Free silica analyses were performed on the portions of settled dust which passed a 325-mesh screen.

The application of special sampling techniques in the routine dust exposure study was limited. Special studies were, however, conducted in laboratories of the Public Health Service and the Bureau of Mines, and in selected mines, to compare the results obtained with several additional dust sampling and quantitation techniques to those obtained by the standard methods used in the routine surveys. These were comparative studies and were not directed to determining occupational exposures per se.

Comparative data were obtained for the following situations or combinations of sampling or quantitation techniques:

1. Standard light field and phase contrast microscopic counts of midget impinger samples.

2. Various combinations of simultaneous or companion samples with midget impingers, cellulose ester membrane filters, thermal precipitators, and a light scattering aerosol photometer in mines and laboratories for particle count and size distribution.
3. Settled dust and companion airborne dust samples for free silica analyses of various fractions separated according to particle size.

Eighty-four midget impinger samples obtained at various mining operations were counted both by the standard light-field microprojector method as used throughout the dust exposure study and by phase contrast microscopy using a 16-mm. (10 power) 0.25-N.A. objective. Since dust particles are detected in light-field microscopic observation by their interference images and in phase contrast microscopy by images resulting from phase shift between diffracted and undiffracted light, which enhances contrast for certain particles, a difference in concentration resulting from counts of the same sample by the two methods may be expected. Nevertheless, the data show a strong relationship between the two methods; the phase contrast count was ordinarily about 1.2 times higher than the companion light field count.

Dust concentrations as determined by light-field and phase contrast counts of midget impinger samples were compared with the concentrations calculated for companion samples obtained by various other methods. Companion samples were obtained with membrane filters, thermal precipitators, and a light scattering aerosol photometer. They were obtained both at mines under normal working conditions and from a laboratory dust chamber under controlled conditions. The coefficients of correlation and ratios of dust concentrations yielded by midget impinger sampling and companion samples by these other methods are shown in table IV.22.

In general, the correlation between impinger results and results by other methods ranged from nominal to good for individual field or laboratory situations in which factors such as particle-size distributions and states of agglomeration would be expected to be reasonably constant. Combinations of data representing a variety of situations in which factors such as size distributions and states of agglomeration could be different resulted generally in lower values for the coefficient of correlation. Even in cases of good correlation between results by two different methods, the ratio of concentrations determined by the two methods might differ substantially from unity. This is to be expected since the methods used may involve such differences as observation of different portions of size distribution curves or the results by the methods being compared may be affected differently by the state of agglomeration of the airborne sample.

TABLE IV.22.—*Comparison of dust concentrations from midget impinger samples with concentrations from companion samples by other methods*

Midget impinger samples	Companion samples	Number of pairs of samples	Coefficient of correlation*	Ratio—mean companion sample concentration; mean midget impinger concentration
Light-field microprojector count, mine samples.	Membrane filter, phase contrast microscope count, 16 mm. objective.	15	0. 67	1. 22
Phase contrast microscope count, mine samples.	Membrane filter, phase contrast microscope count, 16 mm. objective.	14	. 90	1. 01
Light-field microprojector count, laboratory chamber samples, silica dust.	Membrane filter, microprojector count, 16 mm. objective.	20	. 94	1. 12
Light-field microprojector count, laboratory chamber samples, lead-zinc ore dust.	Membrane filter, microprojector count, 16 mm. objective.	16	. 91	. 95
Light-field microprojector count, laboratory chamber samples, mercury ore dust.	Membrane filter, microprojector count, 16 mm. objective.	16	. 81	. 65
Light-field microprojector count, laboratory chamber samples, molybdenum ore dust.	Membrane filter, microprojector count, 16 mm. objective.	16	. 78	. 93
Light-field microprojector count, all laboratory chamber samples.	Membrane filter, microprojector count, 16 mm. objective.	68	. 84	
Light-field microprojector count, mine samples.	Membrane filter, phase contrast microscope count, 1.8 mm. oil immersion objective.	15	. 54	22. 2
Light-field microprojector count, laboratory chamber samples, silica dust.	Thermal precipitator, light-field microprojector count, 16 mm. objective.	20	. 89	2. 63
Light-field microprojector count, laboratory chamber samples, lead-zinc ore dust.	Thermal precipitator, light-field microprojector count, 16 mm. objective.	16	. 88	1. 28
Light-field microprojector count, laboratory chamber samples, mercury ore dust.	Thermal precipitator, light-field microprojector count, 16 mm. objective.	20	. 94	1. 14

*See footnote at end of table.

TABLE IV.22.—*Comparison of dust concentrations from midget impinger samples with concentrations from companion samples by other methods*—Continued

Midget impinger samples	Companion samples	Number of pairs of samples	Coefficient of correlation*	Ratio—mean companion sample concentration; mean midget impinger concentration
Light-field microprojector count, laboratory chamber samples, molybdenum ore dust.	Thermal precipitator, light-field microprojector count, 16 mm. objective.	20	0. 72	1. 93
Light-field microprojector count, all laboratory chamber samples.	Thermal precipitator, light-field microprojector count, 16 mm. objective.	76	. 59	
Light-field microprojector count, surface operation samples.	Thermal precipitator, light-field microprojector count, 16 mm. objective.	5	. 95	1. 54
Light-field microprojector count, mine samples.	Thermal precipitator, phase contrast microscope count only cf particles more than 0.8 micron, 4 mm. objective.	6	. 86	3. 7
Phase contrast microscope count, mine samples.	Thermal precipitator phase contrast microscope count only cf particles more than 0.8 micron, 4 mm. objective.	6	. 98	3. 3
Light-field microprojector count, laboratory chamber samples, silica dust.	Thermal precipitator, light-field microprojector count, 2 mm. oil immersion objective.	20	. 91	6. 7
Light-field microprojector count, laboratory chamber samples, lead-zinc ore dust.	Thermal precipitator, light-field microprojector count, 2 mm. oil immersion objective.	16	. 85	2. 7
Light-field microprojector count, laboratory chamber samples, mercury ore dust.	Thermal precipitator, light-field microprojector count, 2 mm. oil immersion objective.	20	. 93	3. 1

Light-field microprojector count, laboratory chamber samples, molybdenum ore dust.	Thermal precipitator, light-field microprojector count, 2 mm. oil immersion objective.	20	. 97	5. 3
Light-field microprojector count, all laboratory chamber samples.	Thermal precipitator, light-field microprojector count, 2 mm. oil immersion objective.	76	. 69	
Light-field microprojector count, mine samples.	Thermal precipitator, phase contrast microscope counts, 1.8 mm. oil immersion objective.	6	. 84	39. 0
Light-field microprojector count, surface operation samples.	Thermal precipitator, phase contrast microscope counts, 1.8 mm. oil immersion objective.	4	. 98	5. 0
Light-field microprojector count, routine mines survey samples.	Thermal precipitator, light-field microprojector counts, 1.8 mm. oil immersion objective.	25	. 36	9. 7
Light-field microprojector count, mine samples.	Aerosol photometer count, particles more than 0.8 micron.	21	. 89	. 97
Phase contrast microprojector count, mine samples.	Aerosol photometer count, particles more than 0.8 micron.	22	. 71	. 70

$$^{*}r=\frac{n\Sigma XY-\Sigma X\Sigma Y}{\sqrt{[n\Sigma X^2-(\Sigma X)^2][n\Sigma Y^2-(\Sigma Y)^2]}}$$

As stated earlier, free silica determinations have customarily been made on those portions of settled dust samples which pass through a 325-mesh screen. Because airborne particles of different particle sizes do not penetrate and are not retained in the alveoli and noncilliated lung passages in equal proportions, the free silica content of dust in various size ranges is of interest. Relatively few dust particles of the density of quartz and of size greater than about 4.5 microns equivalent diameter penetrate and are retained in the alveolar spaces.

Settled dust samples obtained from various locations in mines and at surface operations were screened through a 325-mesh screen. A portion of each screened sample was air elutriated to obtain a fraction containing only the particles less than 5 microns in diameter. Chemical analysis of these smaller than 5 micron fractions invariably yielded lower free silica contents than did analysis of the unelutriated portion of the samples which passed the 325-mesh screen. In the 56 samples from 27 locations examined in this manner the free silica content of the smaller than 5 microns fraction averaged 48 percent of that of the smaller than 325 mesh fraction. The analytic results for free and total silica content of the samples from these locations are shown in table IV.23.

TABLE IV.23.—*Settled dust samples: free and total silica content of screened fractions and free silica content of air elutriated fractions*

Location	Percent free silica		Percent total silica
	−325 mesh fraction	Less than 5 micron fraction	−325 mesh fraction
1	63	35	71
2	52	28	58
3	34	21	40
4	31	17	32
5	29	9	46
6	27	18	28
7	27	9	36
8	26	9	43
9	24	11	47
10	24	10	44
11	21	13	40
12	21	6	49
13	19	14	32
14	19	12	26
15	18	7	31
16	17	14	43
17	14	6	27
18	13	8	15
19	13	5	23
20	12	4	23
21	10	1	21
22	7	2	15
23–27	Less than 1	Less than 1	4–21

It is recognized that size classification will occur as particles settle out from the air, so settled material does not necessarily represent airborne material either in size distribution or composition. Although the data obtained on these settled dust samples are strong evidence that the free silica content of respirable dust is unlikely to be the same as that of settled dust, they do indicate that some definable relationship between the two may exist. Samples of the respirable fraction of airborne dust, as such, were not obtained. Electrostatic precipitator samples of total airborne dust were, however, obtained in nine underground working places from which settled dust was taken. The average percent free silica for these samples for each location was usually near that of the less than 5 microns fraction of the companion settled dust samples. The airborne dust samples averaged 53 percent of the free silica content of the smaller than 325 mesh fractions of the settled dust while the less than 5 micron fractions averaged 54 percent. Data for these samples are shown in table IV.24. It should be pointed out that the composition of either settled dust or airborne dust is expected to vary from one location to another in a mine, and that airborne dust is expected to vary more in composition than is settled dust.

TABLE IV.24.—*Comparison of free silica content of screened and air elutriated fractions of settled dust with that of companion electrostatic precipitator samples of airborne dust.*

Location	Percent free silica		
	Settled dust samples (18 samples)		Electrostatic precipitator samples (27 samples)
	-325 mesh fraction	Less than 5 micron fraction	
A	63	35	10
B	52	28	23
C	34	21	17
D	31	17	18
E	29	9	14
F	27	18	16
G	26	9	10
H	21	13	14
I	19	12	18

Data from the supplemental studies, which have been summarized here, are of no value at this time for assessing the severity of exposure for interpretation by current standards. They may, however, be of value for reference by investigators in the future who may use instruments similar to those which have been used and may wish some indication of the relationships between these methods, as

applied at this time, and the midget impinger light-field counting method as used in the present study.

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The medical survey unit. (Courtesy of The Bunker Hill Co., 1963.)

CHAPTER V

Medical Study

GENERAL PROCEDURES

THE MEDICAL STUDY was undertaken to determine the prevalence and severity of silicosis in employees of underground metal mines. The study was based primarily upon standard size roentgenograms of the chest, supplemented by medical and occupational histories, and selected tests of pulmonary function. In an attempt to sample a large segment of the metal mining population within a limited time, it was decided not to undertake complete physical examinations or clinical laboratory studies. As medical data other than the brief medical histories were not obtained prior to or after the time of examination at the mine site, there was no study of the development or progression of the disease.

PERSONNEL AND FACILITIES

Medical examinations were made at each mining location by a field team using mobile equipment. The team consisted of a physician who completed the medical and occupational history and screened the X-ray films as to quality, an X-ray technician for taking and processing the chest roentgenograms, a technician for the pulmonary function testing, and an administrative assistant for general administrative and clerical functions. During the 3 years the team was in the field there was occasional turnover and replacement of personnel, but every effort was made to insure a continuity of uniform procedures.

The mobile equipment consisted of a self-contained X-ray truck and generator with equipment for developing, washing, and drying the exposed films. A viewbox was used to screen the films for satisfactory quality, so that workers with unsatisfactory films could be brought back for reexamination. The second vehicle was a house-type trailer fitted with an office for the physician and a laboratory for pulmonary function testing. Logbooks and printed forms were available for recording all phases of the medical examination.

Mines Studied

In general, it was planned to conduct medical examinations at each mine where an environmental study was made. However, this was not possible in all instances. An environmental study was completed at 59 underground metal mines (nonuranium) and 8 uranium mines representing a total of 67 mines. Medical examinations were made at 50 metal mines. Nine metal mines were not included for the following reasons: two mines were closed before the medical team arrived; one mine was at a site inaccessible to the X-ray truck; one mine declined to particiapte in the medical survey after the environmental study was made; the mining operations of one corporation were considered as four separate mines for the environmental study and as two mines for the medical survey; and three mines where the environmental study was conducted had no medical examinations although a separate study of past X-ray readings and work histories was made at one of these mines. The 8 uranium mines included in the engineering study, although not identical with the more than 150 uranium mines which had some workers examined in the medical study, were thought to show the type of conditions which might be encountered.

Examination Procedures

Those employees who volunteered to participate in the study were asked to present themselves according to a prearranged schedule to avoid crowding and undue waiting. In most instances, examinations were limited to off-duty periods, although in some cases, employees were allowed to visit the unit during working hours.

The entire examining procedure took about 20 minutes per man. Each participant was advised at the outset that the medical findings on individuals would be held in the strictest confidence and would not be divulged to the employee, the employer, the union or others outside the Public Health Service. It was explained, however, that should the chest roentgenogram reveal a condition which was thought to need immediate medical attention, the employee's personal physician would be notified if the Public Health Service was so authorized by the employee.

Following the explanation of survey policy, each participant was asked for certain basic information. A brief medical history was then obtained. Although no physical examination was performed, height and weight were measured. A complete occupational history was recorded and the prescribed pulmonary function tests and chest roentgenograms were completed.

The final decision as to whether a worker would present himself for examination was a matter for individual choice. The benefits to be derived from entering the examination program were carefully explained to all the men, but no coercion was applied. Rosters including the names of all workers were supplied to the examining team. These lists were kept up to date as the status of individual workers changed. At the 50 metal mines studied there were 17,208 workers eligible for examination. Of this number, 13,181 or 76.6 percent presented themselves for examination.

The proportion of the total eligible workers who came for examination was 90 percent or over at 8 mines, from 80–89 percent at 19 mines, 70–79 percent at 12 mines, and less than 70 percent at 11 mines.

One way to learn if the workers who came for examination had different characteristics from those who did not come in was to study the age distribution of the two groups. This type of analysis was possible using the available records from 36 mines which included 71 percent of all workers. Table V.I shows the percent according to age of all eligible workers who were examined. It will be observed that from 25 through 59 years of age three-fourths of the workers were examined. A smaller percentage of the younger men were included. Men 60 years of age and over were very slightly under-represented compared with the middle age group.

Among underground workers 72.1 percent were examined as compared with 78.4 percent for surface workers. The difference was concentrated in the groups under 50 years of age, while for workers above this age the percent of underground and surface workers examined was nearly the same.

There was a tendency for men to transfer from underground to surface work as they become older and less fit for hard labor, but if any large group of potentially silicotic older men failed to appear for examination this table does not indicate it.

Apparently a wide variety of factors influenced the decision of the workers to take or not take the physical examination. A major reason for nonparticipation was absence from work at the time of the survey because of vacation, temporary illness or other reasons. Failure to come for examination was frequently attributed to the use of carpools for commuting workers. In many instances, one man would not wish to delay the other members of his carpool. Sometimes men refused to come when they learned it was to be on their own time. Other men had a dislike and suspicion of any medical examination. A determined effort was made by the medical team to get all workers to come for examination. Management and union help was solicited and various publicity methods were used.

TABLE V.1.—*Workers at 36 metal mines who were eligible for a medical examination and those examined according to age and place working*

Age in years	All workers			Underground workers			Surface workers		
	Total eligible for examination	Examined		Total eligible for examination	Examined		Total eligible for examination	Examined	
		Number	Percent		Number	Percent		Number	Percent
Total	11, 666	8, 586	73. 6	8, 881	6, 403	72. 1	2, 785	2, 183	78. 4
Less than 20	161	79	49. 1	122	53	43. 4	39	26	66. 7
20–24	951	593	62. 4	793	477	60. 2	158	116	73. 4
25–29	1, 307	944	72. 2	1, 103	772	70. 0	204	172	84. 3
30–34	1, 690	1, 306	77. 3	1, 408	1, 069	75. 9	282	237	84. 0
35–39	1, 574	1, 187	75. 4	1, 266	942	74. 4	308	245	79. 5
40–44	1, 670	1, 280	76. 6	1, 277	955	74. 8	393	325	82. 7
45–49	1, 585	1, 189	75. 0	1, 137	832	73. 2	448	357	79. 7
50–54	1, 338	996	74. 4	933	692	74. 2	405	304	75. 1
55–59	822	619	75. 3	529	397	75. 0	293	222	75. 8
60 and over	568	393	69. 2	313	214	68. 4	255	179	70. 2

Physician interviewing a miner.

Medical History and Symptoms

Each participant was questioned as to present or past history of the following disease conditions: tuberculosis, pneumonia, pleurisy, bronchitis, asthma, heart trouble, rheumatic fever, rheumatism, lead poisoning, "dust on your lungs," and mercurial poisoning. It was felt that the answers to these questions would be helpful in evaluating the chest roentgenographic findings. In addition, each worker was asked whether he ever noted wheezy or whistling sounds in his chest and, if so, whether these sounds occurred only with colds or at other times as well. Frequency of chest colds attended by sputum production was also recorded. Finally, a complete history of severity and duration of each chest illness necessitating absence from work during the previous 3 years was elicited (see figure V.1).

The symptom of breathlessness was evaluated in each case through obtaining answers to a series of questions similar to those designed by British investigators,[1] * for the purpose of quantitating this subjective complaint.

FIGURE V.1.—Medical examination form

Medical history and symptoms

Have you ever had, or been told you had:
(If YES, check and give year or years)

a. Tuberculosis	______	g. Rheumatic fever	______
b. Pneumonia	______	h. Rheumatism	______
c. Pleurisy	______	i. Lead poisoning	______
d. Bronchitis	______	j. Dust on your lungs	______
e. Asthma	______	k. Mercurial poisoning	______
f. Heart trouble	______		

Remarks____

Does your chest ever sound wheezy or whistling? YES NO

If YES, only with colds?______ Or at other times?______

If you get a cold, does it usually go to your chest? YES NO
(NOTE to examiner: Only record YES if more than half of colds are followed by cough and sputum.
For those who never get colds, record NO; for those who only have chest colds, record YES.)

During the past 3 years, have you had a chest illness which has kept you in bed, off work, or indoors at home? YES NO
If NO, check, not even flu?

*Numbers refer to list of references at the end of the chapter.

If YES, give:

Doctor's diagnosis, if known	Duration in days	Year

Questions on breathlessness

Are you troubled by shortness of breath? Check: Not even on hurrying on level or walking up a slight hill?	YES	NO
If YES: Do you have to walk more slowly than men of your own age when climbing hills or stairs?	YES	NO
Do you have to walk more slowly than people of your own age on the level?	YES	NO
Do you have to stop for breath after walking 100 yards or after walking a few minutes on the level?	YES	NO
Do you get short of breath while talking or undressing, or are you ever too short of breath to leave the house?	YES	NO

GRADING OF SHORTNESS OF BREATH (after obtaining above answers)	CIRCLE ONE
a. Is breath as good as other men of his own age and build at work, on walking, and on climbing hills or stairs?	1
b. Is patient able to walk with normal men of own age and build on the level but unable to keep up on hills or stairs?	2
c. Is patient unable to keep up with normal men on the level, but able to walk a mile or more at his own speed?	3
d. Is patient unable to walk more than about 100 yards on the level without a rest?	4
e. Is patient short of breath on talking or undressing, or or unable to leave his house because of shortness of breath?	5

Occupational History

Starting with his present job, each worker was asked to recall to the best of his ability, the type, geographical location, duration, dust control measures, and environmental conditions of each previous job. Within the limitations of this method of personal interview, it was hoped to obtain a reasonably valid and complete work history from every participant. This information was recorded as seen in figure V.2.

FIGURE V.2.—Occupational history form

Present job:

Dates: From: *1954* to *1958.*
Name of mine or company: *Acme Mining Co.*
Town and State: *Tall Pine, Idaho.*
Kind of mine or industry: *Lead-zinc.*
I. Your job: *Miner—Square set stope.*
II. Actual work done: *All mining tasks.*
III. Special conditions: *Wet drilling—mechanical ventilation.*

Previous jobs:

Dates; From: *1946* to *1954.*
Name of mine or company: *Ajax Mining Co.*
Town and State: *Centralia, Ariz.*
Kind of mine or industry: *Copper.*
I. Your job: *Motorman.*
II. Actual work done: *Chute pulling.*
III. Special conditions: *Muck dry, natural ventilation.*

Dates; From: *1940* to *1946.*
Name of mine or company: ____________.
Town and State: *Various locations—Colorado.*
Kind of mine or industry: *Ranch land.*
I. Your job: ____________.
II. Actual work done: ____________.
III. Special conditions: ____________.

Chest Roentgenograms

A 14- by 17-inch chest roentgenogram was taken of each participating worker. These films were taken using a 200-milliampere mobile unit fitted with a 1.5-mm. aluminum filter. Each film was taken at 72 inches with the worker in a posterior-anterior position. Exposed films were developed in the unit, usually at the mine site, and immediately screened by the team physician. In cases where the film was thought to be technically unsatisfactory, the worker was contacted when possible, and asked to return for a repeat roentgenogram. If preliminary screening revealed a condition which was thought to be of such a nature as to require immediate medical attention, such as suspect cancer or active tuberculosis, the participant was advised to see his personal physician. All films were then sent to the Occupational Health Research and Training Facility at Cincinnati for recording and distribution to the panel of radiological consultants.

Two simple pulmonary function tests were performed by each participant unless maximal respiratory exertion was thought by the team physician to be contraindicated. These tests were obtained by a technician who had been trained to urge the maximum effort for each subject. His work was frequently observed by the team physician in an effort to assure a high standard of performance. Test results which were thought to be technically unsatisfactory were so labeled.

The two tests that were performed were the forced expirogram and the maximum forced expiratory flow rate. The forced expirogram was obtained with the use of a 6-liter Collins recording vitalometer. Forced vital capacity and 1 second forced expiratory volume were measured using this method. In addition, the ratio of 1.0 sec. FEV/FVC was calculated. The maximum forced expiratory flow rate was measured by means of the peak-flow meter described by Wright and McKerrow.[2]

Forced Expirogram

Following an explanation and demonstration of the test by the technician, the subject was asked to take a maximum inspiration, place the mouthpiece of the recording vitalometer well into his mouth and blow out as hard and as fast and as long as possible. The subject was repeatedly urged to obtain his maximum effort. The test was repeated several times in order to obtain three satisfactory recordings. From the resulting kymograph tracing, the forced vital capacity (FVC) and first second forced expiratory volume (FEV_1) were calculated. Of the several tracings obtained, the one curve demonstrating the best FVC was used in calculating FVC, 1 second FEV, and FEV_1/FVC.

Maximum Forced Expiratory Flow Rate

This test of maximum flow rate or peak expiratory flow (PEF) was accomplished by asking the subject to take a deep breath, as for the forced spirogram, place the mouthpiece * of the instrument into his mouth, and then to blow into the instrument as hard as he could. The results of the test were read directly from the dial as liters per minute and recorded. The test was repeated several times and the best effort taken as the subject's final score.

*The disposable mouthpieces provided for the Collins vitalometer were also used for this test with the peak–flow meter. The internal diameter of the mouthpiece was three-fourths inch.

Conditions of Testing

It is emphasized that these tests were made under field working conditions in a house-type trailer, and at the various mine sites in different parts of the country as previously described. Ample time for careful training and testing of the metal mine workers was available during some working schedules, while others were necessarily somewhat hurried owing to uncontrollable circumstances. All workers were repeatedly urged to make their best effort. The ambient temperatures within the trailer were not utilized in the calculations of the pulmonary function measurments, but they were usually about 25° C. Since temperature corrections were not made, the values obtained included some degree of error. However, since this error was introduced in all measurements, the comparisons between groups of subjects were not affected. Temperature control was facilitated by scheduling the visits to mines in northern states in the summer months, and to the southern states during the winter. Workers were tested at all times of the day with relation to the working shifts but principally before or after the daily work shift.

Analyses of the pulmonary function data could not be completed satisfactorily in time for the preparation of this publication, but certain preliminary analyses and interpretations based upon a simple multiple regression calculation technique are presented in appendix A.

CHARACTERISTICS OF WORKERS EXAMINED

Age and Occupation

Tables V.2 and V.3 show the age of metal mine workers according to principal occupation and present occupation. The *principal* occupation was the type of work performed during more than half the time a man was engaged in metal mining with the additional provision that all persons who worked 10 years or more at the mine face were classified as face miners. The *present* occupation represented the kind of work a man was doing at the time he was interviewed for the medical examination. Excluding persons who had not worked steadily at any one job, the principal occupation for almost three-fourths of the workers was located underground. Workers according to principal occupation were distributed as follows: Underground face, 47.1 percent; underground transportation, 11.2 percent; underground maintenance and construction, 10.4 percent; other underground work, 5.9 percent; surface transportation, 2.7 percent; surface maintenance and construction, 9.5 percent; surface mill, 6.9 percent; and other surface workers, 6.3 percent.

A miner performing a pulmonary function test.

TABLE V.2.—*Principal occupation of workers at 50 metal mines* according to age*

Principal occupation	Total	Age in years			
		Under 35	35–44	45–54	55 and over
	Number				
Total	12, 487	4, 136	3, 627	3, 184	1, 540
Underground total	8, 435	2, 792	2, 559	2, 127	957
Face	5, 330	1, 728	1, 678	1, 332	592
Transportation	1, 265	473	359	307	126
Maintenance and construction	1, 171	381	321	312	157
Other underground work	669	210	201	176	82
Surface total	2, 870	755	790	833	492
Transportation	307	85	106	82	34
Maintenance and construction	1, 074	242	280	347	205
Mill	777	249	190	224	114
Other surface work	712	179	214	180	139
No principal occupation	1, 182	589	278	224	91
	Percent				
Total	100. 0	33. 1	29. 1	25. 5	12. 3
Underground total	100. 0	33. 1	30. 3	25. 2	11. 4
Face	100. 0	32. 4	31. 5	25. 0	11. 1
Transportation	100. 0	37. 4	28. 4	24. 2	10. 0
Maintenance and construction	100. 0	32. 5	27. 4	26. 7	13. 4
Other underground work	100. 0	31. 4	30. 0	26. 3	12. 3
Surface total	100. 0	26. 3	27. 5	29. 0	17. 2
Transportation	100. 0	27. 7	34. 5	26. 7	11. 1
Maintenance and construction	100. 0	22. 5	26. 1	32. 3	19. 1
Mill	100. 0	32. 0	24. 5	28. 8	14. 7
Other surface work	100. 0	25. 1	30. 1	25. 3	19. 5
No principal occupation	100. 0	49. 8	23. 6	18. 9	7. 7

*Excludes uranium mine workers.

TABLE V.3.—*Present occupation of workers at 50 metal mines* according to age*

Present occupation	Total	Age in years			
		Under 35	35–44	45–54	55 and over
	Number				
Total	12, 487	4, 136	3, 627	3, 184	1, 540
Underground total	8, 838	3, 179	2, 672	2, 116	871
Face	4, 474	1, 788	1, 474	943	269
Transportation	1, 468	564	413	350	141
Maintenance and construction	1, 818	505	468	518	327
Other underground work	1, 078	322	317	305	134
Surface total	3, 649	957	955	1, 068	669
Transportation	424	108	143	113	60
Maintenance and construction	1, 404	340	350	456	258
Mill	898	300	207	245	146
Other surface work	923	209	255	254	205
	Percent				
Total	100. 0	33. 1	29. 1	25. 5	12. 3
Underground total	100. 0	36. 0	30. 2	24. 0	9. 8
Face	100. 0	40. 0	33. 0	21. 0	6. 0
Transportation	100. 0	38. 4	28. 1	23. 9	9. 6
Maintenance and construction	100. 0	27. 8	25. 7	28. 5	18. 0
Other underground work	100. 0	29. 9	29. 4	28. 3	12. 4
Surface total	100. 0	26. 2	26. 2	29. 3	18. 3
Transportation	100. 0	25. 5	33. 7	26. 7	14. 1
Maintenance and construction	100. 0	24. 2	24. 9	32. 5	18. 4
Mill	100. 0	33. 4	23. 1	27. 3	16. 2
Other surface work	100. 0	22. 7	27. 6	27. 5	22. 2

*Excludes uranium mine workers.

Age distribution by principal occupation shows that surface workers were older than underground workers: 17.2 percent as compared with 11.4 percent were 55 years of age and over. Faceworkers, and underground and surface transportation workers, had a small proportion in the oldest age group. Maintenance and construction workers, both underground and on the surface, millworkers, and miscellaneous surface workers showed a relatively large percentage 55 years of age

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and over. Similar age trends were observed when these workers were classified by present occupation. The most marked difference was the greater percent of young men currently employed as faceworkers. This was due in part to the fact that all men with 10 years or more at the working face were classified as faceworkers in regard to their principal occupation.

Years in Principal Occupation

Table V.4 shows the number of years that men had worked at each of eight principal metal mine occupations. Workers with the longest metal mining experience were found in surface occupations which showed 11.1 percent of the total with 30 years or more, compared with 8.3 percent for the same duration group among underground workers. The percent of employees with 30 years or more of experience was 13.8 for surface maintenance and construction workers, 13.4 percent for miscellaneous surface workers, 12.6 percent for miscellaneous underground workers, 9.2 percent for surface transportation workers, 8.6 percent for underground faceworkers, and less than 7 percent for underground transportation and maintenance and construction workers and surface millworkers.

Approximately one-fourth of the underground transportation, maintenance and construction, and miscellaneous workers had less than 5 years of metal mine experience. Among surface workers only those in the mill had a similarly short experience. Other surface occupations each had less than 18 percent in the under-5-year group.

Years in Present Occupation

Table V.5 shows that nearly half (47 percent) of all underground workers had been at their present job for less than 5 years. A smaller proportion of surface workers (38.7 percent) had been in their job less than 5 years. Persons on the surface had been at the same job longer than those underground. Except for millworkers more than one-fifth of the workers in surface occupational groups had held their present job for 15 years or longer. From 10.7 to 14.9 percent of the groups of underground workers had 15 years or longer in the same occupation.

The occupational history interview.

TABLE V.4.—*Principal occupations of workers at 50 metal mines* according to years worked at metal mines*

Principal occupation	Years at metal mines								
	Total	–5	5–9	10–14	15–19	20–24	25–29	30–34	35+
	Number								
Total	12, 487	2, 838	2, 573	2, 169	1, 814	1, 350	666	555	522
Underground total	8, 435	1, 730	1, 817	1, 557	1, 245	937	444	390	315
Face	5, 330	909	1, 180	1, 101	773	612	292	259	204
Transportation	1, 265	336	276	198	196	119	57	42	41
Maintenance and construction	1, 171	319	250	166	182	125	48	41	40
Miscellaneous	669	166	111	92	94	81	47	48	30
Surface total	2, 870	542	606	463	452	314	174	135	184
Transportation	307	47	69	58	55	33	17	10	18
Maintenance and construction	1, 074	175	217	181	161	119	73	62	86
Mill	777	199	171	113	140	70	36	21	27
Miscellaneous	712	121	149	111	96	92	48	42	53
No principal occupation	1, 182	566	150	149	117	99	48	30	23

	Percent								
Total	100. 0	22. 7	20. 6	17. 4	14. 5	10. 8	5. 3	4. 5	4. 2
Underground total	100. 0	20. 5	21. 5	18. 5	14. 8	11. 1	5. 3	4. 6	3. 7
Face	100. 0	17. 1	22. 1	20. 7	14. 5	11. 5	5. 5	4. 8	3. 8
Transportation	100. 0	26. 5	21. 8	15. 7	15. 5	9. 4	4. 5	3. 4	3. 2
Maintenance and construction	100. 0	27. 2	21. 3	14. 2	15. 5	10. 7	4. 2	3. 5	3. 4
Miscellaneous	100. 0	24. 8	16. 6	13. 8	14. 1	12. 1	7. 0	7. 1	4. 5
Surface total	100. 0	18. 9	21. 1	16. 1	15. 8	10. 9	6. 1	4. 7	6. 4
Transportation	100. 0	15. 3	22. 5	18. 9	17. 9	10. 7	5. 5	3. 3	5. 9
Maintenance and construction	100. 0	16. 3	20. 2	16. 9	15. 0	11. 0	6. 8	5. 8	8. 0
Mill	100. 0	25. 6	22. 0	14. 6	18. 0	9. 0	4. 6	2. 7	3. 5
Miscellaneous	100. 0	17. 0	20. 9	15. 6	13. 5	12. 9	6. 7	5. 9	7. 5
No principal occupation	100. 0	48. 0	12. 6	12. 6	9. 9	8. 4	4. 0	2. 5	2. 0

*Excludes uranium mine workers.

TABLE V.5.—*Present occupation of workers at 50 metal mines* according to years in present occupation*

Present occupations	Years in present occupation											
	Number						Percent					
	Total	−5	5–9	10–14	15–19	20+	Total	−5	5–9	10–14	15–19	20+
Grand total	12, 487	5, 563	3, 074	1, 874	1, 033	943	100. 0	44. 6	24. 6	15. 0	8. 3	7. 5
Underground total	8, 838	4, 151	2, 206	1, 290	658	533	100. 0	47. 0	25. 0	14. 6	7. 4	6. 0
Face	4, 474	1, 908	1, 237	705	360	264	100. 0	42. 7	27. 6	15. 8	8. 0	5. 9
Transportation	1, 468	867	290	154	91	66	100. 0	59. 0	19. 8	10. 5	6. 2	4. 5
Maintenance and construction	1, 818	903	406	260	119	130	100. 0	49. 7	22. 3	14. 3	6. 5	7. 2
Miscellaneous	1, 078	473	273	171	88	73	100. 0	43. 9	25. 3	15. 9	8. 2	6. 7
Surface total	3, 649	1, 412	868	584	375	410	100. 0	38. 7	23. 8	16. 0	10. 3	11. 2
Transportation	424	167	101	71	49	36	100. 0	39. 4	23. 8	16. 7	11. 6	8. 5
Maintenance and construction	1, 404	490	348	240	141	185	100. 0	34. 9	24. 8	17. 1	10. 0	13. 2
Mill	898	408	210	131	89	60	100. 0	45. 4	23. 4	14. 6	9. 9	6. 7
Miscellaneous	923	347	209	142	96	129	100. 0	37. 6	22. 6	15. 4	10. 4	14. 0

*Excludes uranium mine workers.

ANALYSIS OF MEDICAL FINDINGS

Analysis of Chest Roentgenograms

General Procedure

The chest roentgenogram is the most important diagnostic tool for determining the prevalence of silicosis or most other types of pneumoconiosis in a study of an industrial population. It was recognized that a careful and complete clinical study is necessary to appraise the nature and degree of pulmonary disease and associated disability in a given individual and should be made in hospitals and clinics where such medical evaluations could be made. Nevertheless, experience over the past several decades has shown that an X-ray survey in an industry with a pneumoconiosis-producing dust hazard can give an accurate cross-section index of workers with the characteristic X-ray film changes associated with the disease.

In view of the importance of obtaining impartial and highly experienced physicians to read and interpret the chest roentgenograms obtained in this study and to insure a minimum of error in film interpretations, a panel of three highly qualified radiologists was selected for the purpose. It was agreed that each would read and classify each chest film independently without any knowledge of the miner or his occupational history and submit their individual findings for collation and analysis. Quarterly meetings of the panel were held to discuss and resolve any areas of disagreement resulting from the individual readings. Finally a group reading or consensus was entered on the records for each film. If any disagreement persisted, a majority reading was entered.

Classification of Roentgenograms

In earlier studies of silicosis and other types of pneumoconiosis made by the Public Health Service, several X-ray classifications of pneumoconiotic chest films had been developed or adapted for the purpose. These classifications were described in some detail in Public Health Service bulletins reporting studies of granite cutters published in 1929,[3] pottery workers in 1939,[4] of metal mine workers in 1942,[5] of anthracite miners in 1936,[6] of soft coal miners in 1941,[7] and workers in the diatomite mining and processing industry in 1958.[8]

In the present study, the panel of radiological consultants agreed to classify pneumoconiotic changes appearing in the chest films according to the newly revised "International Classification of Persistent Radiological Opacities in the Lung Fields Provoked by the Inhalation of Mineral Dusts." This revised international classification was

adopted at a meeting of experts in 1958, and was published and promulgated by the International Labour Office early in 1959.[9] Sets of I.L.O. standard reference chest films illustrating the various categories of pneumoconiotic changes were distributed for use when they became available.

The use of this descriptive classification permits a comparison of the nature and degree of pneumoconiotic changes between employees, industries and also between countries, thereby facilitating epidemiological studies of pneumoconiosis problems and the evaluation of public health programs for prevention of these dust-induced pulmonary diseases. The I.L.O. classification is not intended to define pathological entities, or to take into account the question of working capacity. It has no relation to the legal definition of stages of pneumoconiosis for compensation purposes. (See ch. VII.)

A slightly modified schematic representation of the 1958 I.L.O. classification is shown in figures V.3 and V.4. All the films in this study were classified according to this detailed scheme. In presenting the data for the purpose of this report, the film readings were presented in four broad groupings according to their relative degree of medical significance. These groupings were as follows:

- Negative films or no pneumoconiosis—healthy or normal chest.
- Suspect films—"suspect," "doubtful," or "borderline" silicosis.*
- Small opacities including categories 1, 2, and 3—simple silicosis.*
- Large opacities including categories A, B, and C—complicated silicosis.*

It should be emphasized that these groupings were based upon objective chest film interpretations and were classified by a panel of three experienced radiologists who had no knowledge of the individual miner's occupational history, medical history, or physical condition. The classification is not intended to imply any degree of physical disability or to define pathological entities. The classification does indicate that the films are consistent with a diagnosis of simple or complicated pneumoconiosis.

Roentgenograms Classified as Silicotic

In this study, a grand total of 14,959 persons appeared for medical examination. Satisfactory chest roentgenograms were obtained upon 14,858 of these persons. Of these films, 522 were classified by the radiological panel as consistent with a diagnosis of silicosis, resulting in a crude rate of 3.5 percent for *all* 14,858 X-ray readings. In analyz-

*Although the I.L.O. classification always uses the generic term "pneumoconiosis", the term "silicosis" is generally used in reporting the results of this study since silicosis is the type of pneumoconiosis commonly found in metal miners exposed at mining operations in hard rock and silica-bearing ore bodies.

FIGURE V.3.—*International Radiological Classification of Chest Films Modified for Public Health Service Metal Mines Survey*

Type of opacity	Film quality		No pneumoconiosis	Doubtful or suspect	Pneumoconiosis														
					Small opacities									Large opacities*				Eggshell† calcification	
Quantitative features.					1			2			3								
Qualitative features.	Unsatisfactory film.	Poor film.	0	Z	p	m	n	p	m	n	p	m	n	AX	A	B	C	Positive.	Suspect.

Additional symbols.	co	cp	cv	di	em	hi	pl	px	tb	ca	cn	nt	ns

Code for Additional Symbols

co—abnormal cardiac outline, excluding cp.
cp—cor pulmonale.
cv—cavity.
di—significant distortion.
em—marked emphysema.
hi—marked abnormal hilar shadows.
pl—significant pleural abnormalities.
px—pneumothorax.
tb—tuberculosis suspect.
ca—cancer suspect.
cn—calcified nodules in small opacities.
nt—nontuberculous infection.
ns—probably nonsilicotic.

*The background of small opacities should be specified as far as possible.
†See definitions—fig. V.4.

FIGURE V.4.—*Definition of Terms Used in Public Health Service Modification of I.L.O. Radiological Classification of Chest Films for Metal Mines Survey*

Film quality.	Unsatisfactory film—impossible to read. Poor film—film of such quality as to make detailed classification difficult.
No pneumoconiosis.	O—No radiographic evidence of pneumoconiosis in lung fields.
Doubtful or suspect opacities.	Z—Lung markings which are suspect for silicosis but are insufficient to be placed in a category of small opacities.
Small opacities.	These categories depend on the extent and the profusion of the opacities: Category 1: A small number of opacities in an area equivalent to at least 2 anterior rib spaces and at the most not greater than one-third of the 2 lung fields. Category 2: Opacities more numerous and diffuse than in category 1 and distributed over most of the lung fields. Category 3: Very numerous profuse opacities covering the whole or nearly the whole of the lung fields. The following types are defined according to the greatest diameter of the predominant opacities: p: Punctiform opacities. Size up to 1.5 mm. m: Micronodular or miliary opacities. Greatest diameter between 1.5 mm. and 3 mm. n: Nodular opacities. Size between 3 and 10 mm.
Large opacities.	AX: Suspicion of large opacities or coalescence. A: An opacity having a longest diameter of between 1 and 5 cm. or several opacities each greater than 1 cm. the sum of whose longest diameter does not exceed 5 cm. B: 1 or more opacities, larger or more numerous than those in category A whose combined area does not exceed ⅓ of 1 lung field. C: 1 or more large opacities whose combined area exceeds ⅓ of 1 lung field.
Eggshell calcifications.	Specific criteria for identifying eggshell calcifications as evidence of silicosis: (1) The presence of shell-like calcifications measuring up to 2 mm. in thickness in the peripheral zone of at least 2 lymph nodes. (2) These calcifications may be solid or broken. (3) In at least 1 of the lymph nodes the ringlike shadow must be complete. (4) The central portions of the lymph nodes may show, in addition, speckled calcification. (5) The affected lymph node must be at least 1 cm. in its greatest diameter. A category of "suspect" eggshell calcification, representing findings which do not quite meet the above criteria, has been included for epidemiologic purposes only.

ing positive film readings, 337 or 2.3 percent of the total were classified as simple silicosis and 185 or 1.2 percent were considered to be complicated silicosis. The crude silicosis rate, therefore, for all metal mine employees examined was 3.5 percent, of whom about one-third were classified as complicated silicosis.*

X-ray findings on the total mining population examined in the study might not present a true picture of the prevalence of silicosis in the metal mines included in the survey. A rather common situation was the case of a silicotic miner who had also worked in other dusty trades such as coal mining, foundries, or smelters for substantial periods during his working life. Therefore, persons employed for 5 or more years in other dusty work, were excluded from the study group upon which detailed analyses had been made.

In all there were 883 persons out of the grand total of 14,959 examined who were excluded from the study group for the following reasons:

Workers with incomplete records	130
Workers considered nonminers	82
Workers with 5 or more years in other dusty work not related to metal mining	671
Total excluded	883

The exclusion of these 883 persons including 46 cases of silicosis from the total group who appeared for examination leaves a study group of 14,076 persons who were considered to be *bona fide* metal mine workers. This was the sample population of metal miners upon which the following detailed analyses has been made. In certain tables the 1,589 workers in uranium mines have been excluded leaving a total of 12,487 men in 50 metal mines.

The prevalence of metal mine workers with X-ray evidence of silicosis is shown in tables V.6 and V.7. Within the study group of 14,076 metal mine workers, there were 476 or 3.4 percent with chest films classified as silicotic. This ratio of positive cases varied greatly from mine to mine ranging from 12.9 percent at one mine to none at seven mines, the median figure being 3 percent. It is of considerable interest that 13 mines had less than 1 percent silicosis while only 5 mines had more than 7 percent silicosis. The remaining 32 mines were rather evenly distributed with crude percentage rates ranging from 1 up to 7 percent.

Although the overall proportion of simple to complicated silicosis films in this group was roughly two to one, there was considerable variation from mine to mine. Another striking feature in analyzing these crude figures mine by mine was the paucity of silicosis cases at many mines and the heavy grouping of cases at a few other mines.

* See prevalence rate of 3.4 percent for the study group, table V.7.

TABLE V.6.—*Distribution of 50 metal mines* according to prevalence of silicosis*

Percentage range of silicosis cases	Number of mines	Workers examined	
		Number	Percent of total
None	7	1, 081	8. 7
0.1–0.9	6	1, 829	14. 6
1.0–1.9	7	1, 584	12. 7
2.0–2.9	5	1, 501	12. 0
3.0–3.9	5	489	3. 9
4.0–4.9	8	3, 574	28. 6
5.0–5.9	2	400	3. 2
6.0–6.9	5	1, 138	9. 1
7.0–7.9	1	(†)	. 1
8.0–8.9	0	------	------
9.0–9.9	1	(**)	3. 5
10.0–10.9	2	283	2. 3
11.0–11.9	0	------	------
12.0–12.9	1	(‡)	1. 3

*Excludes uranium mine workers.
†Less than 50 workers.
**Between 400 and 500 workers.
‡Between 100 and 200 workers.

Figure V.5 shows the distribution of the number of simple and complicated cases on a mine-by-mine basis, ignoring rates based on mine population.

Figure V.5 shows that seven mines had no silicosis. In addition to these, 14 mines had from 1 to 4 cases of simple silicosis but no complicated silicosis. Three other mines had no simple silicosis but two or three cases of complicated silicosis. Another grouping of 11 mines had from 1 to 4 cases of simple silicosis and also from 1 to 3 cases of complicated silicosis. Hence, a heavy concentration of silicosis cases occurred in the remaining 15 mines that had more than 7 cases of silicosis with a wide scattering of both simple and complicated cases.

Table V.7 shows for each mine the percent of workers with simple and with complicated silicosis, the prevalence of silicosis among workers with 10 years or more and 20 years or more experience in metal mining, and the percentage distribution of persons examined according to years worked at metal mines. Mines were grouped according to size, namely, those with less than 100 employees, mines with 100–299 employees, mines with 300–699 employees, and mines with 700 or more employees. Uranium mines, most of which had less than 25 employees, were placed under a separate heading.

It may be noted that within each size group, individual mines showed great variation in the prevalence of silicosis. This was un-

TABLE V.7.—*Percent of metal mine workers with X-ray evidence of silicosis according to size of mine and number of years worked at 50 metal mines and uranium mines*

Percent of workers with silicosis					Percent of workers with specified number of years of experience at metal mines		
According to type			According to years worked at metal mines				
Total	Simple	Complicated	10 years or more	20 years or more	Less than 10	10–19	20 or over
Total for all mines							
3.4	2.2	1.2	6.2	11.6	46	31	23
Mines with less than 100 employees							
Total 4.2	2.4	1.8	8.2	13.2	50	29	21
10.5	10.5	0	20.0	0	*47	*37	*16
7.7	7.7	0	7.7	*11.1	0	*31	*69
6.7	1.7	5.0	12.5	21.4	47	30	23
6.5	4.3	2.2	10.5	21.1	38	41	21
4.3	1.4	2.9	9.7	13.3	55	23	22
3.7	0	3.7	7.1	18.2	48	32	20
3.0	3.0	0	3.3	5.3	*9	33	58
2.7	2.7	0	*12.5	*16.7	79	*5	*16
1.8	1.8	0	4.5	0	61	25	*14
0	0	0	0	0	*43	52	*5
0	0	0	0	0	79	19	*2
Mines with 100–299 employees							
Total 3.4	2.2	1.2	5.3	9.6	38	37	25
12.9	8.6	4.3	18.4	23.3	30	33	37
10.6	8.0	2.6	19.3	36.2	47	35	18
5.2	3.0	2.2	12.8	25.0	65	20	15
4.7	2.6	2.1	9.0	19.0	48	30	22
4.6	2.3	2.3	10.9	16.7	59	28	13
4.0	2.3	1.7	7.1	13.2	43	35	22
3.8	2.3	1.5	5.2	28.6	28	62	10
3.4	1.7	1.7	3.9	7.1	12	40	48
3.2	0	3.2	4.2	13.6	22	54	24
2.8	1.7	1.1	3.6	5.2	23	35	42
2.6	2.6	0	3.0	2.7	11	25	64
1.7	1.7	0	3.0	6.9	44	31	25
1.6	.8	.8	6.3	*33.3	76	20	*4
1.1	0	1.1	2.6	9.5	56	32	12
1.0	1.0	0	1.4	1.7	25	44	31
.7	.7	0	0	0	50	33	17
.6	.6	0	.6	1.2	9	43	48
.4	.4	0	.7	2.2	39	42	19
0	0	0	0	0	42	53	*5
0	0	0	0	0	36	55	9
0	0	0	0	0	27	31	42

TABLE V.7.—*Percent of metal mine workers with X-ray evidence of silicosis according to size of mine and number of years worked at 50 metal mines and uranium mines*—Continued

	Percent of workers with silicosis					Percent of workers with specified number of years of experience at metal mines		
	According to type			According to years worked at metal mines				
	Total	Simple	Complicated	10 years or more	20 years or more	Less than 10	10–19	20 or over
Mines with 300–699 employees								
Total	4. 0	2. 8	1. 2	5. 5	9. 7	28	36	36
	9. 7	6. 5	3. 2	10. 2	21. 3	5	57	38
	6. 0	4. 9	1. 1	6. 0	6. 9	*1	12	87
	6. 0	4. 9	1. 1	10. 5	24. 1	50	30	20
	5. 3	3. 0	2. 3	10. 7	23. 5	51	30	19
	4. 0	2. 8	1. 2	5. 8	9. 6	30	35	35
	2. 4	1. 3	1. 1	3. 3	6. 4	27	39	34
	1. 4	. 7	. 7	3. 4	8. 3	62	22	16
	. 9	. 9	0	1. 0	1. 6	5	38	57
	. 3	. 3	0	. 4	1. 0	27	40	33
Mines with 700 or more employees								
Total	3. 3	2. 0	1. 3	6. 5	12. 9	54	27	19
	6. 2	4. 3	1. 9	11. 4	27. 0	46	33	21
	4. 3	2. 7	1. 6	7. 3	14. 4	42	35	23
	4. 3	1. 5	2. 8	8. 9	19. 1	52	27	21
	4. 0	2. 5	1. 5	18. 7	37. 9	80	14	6
	2. 8	2. 1	. 7	4. 6	10. 9	39	36	25
	1. 6	1. 0	. 6	5. 4	11. 1	70	23	7
	. 6	. 6	0	. 6	. 9	4	47	49
	0	0	0	0	0	91	8	*1
	0	0	0	0	0	90	7	3
Uranium mines								
	3. 2	2. 1	1. 1	10. 3	27. 3	70	21	9

*Based on less than 10 employees in exposure group.

doubtedly due to many factors, some of which represented a genuine difference in the silicosis hazard while others were merely a reflection of the age and work experience of the population at risk. It is apparent that where a large proportion of the workers were in the older age groups with long mining experience the silicosis rate would be higher than in younger populations even though the risks were the

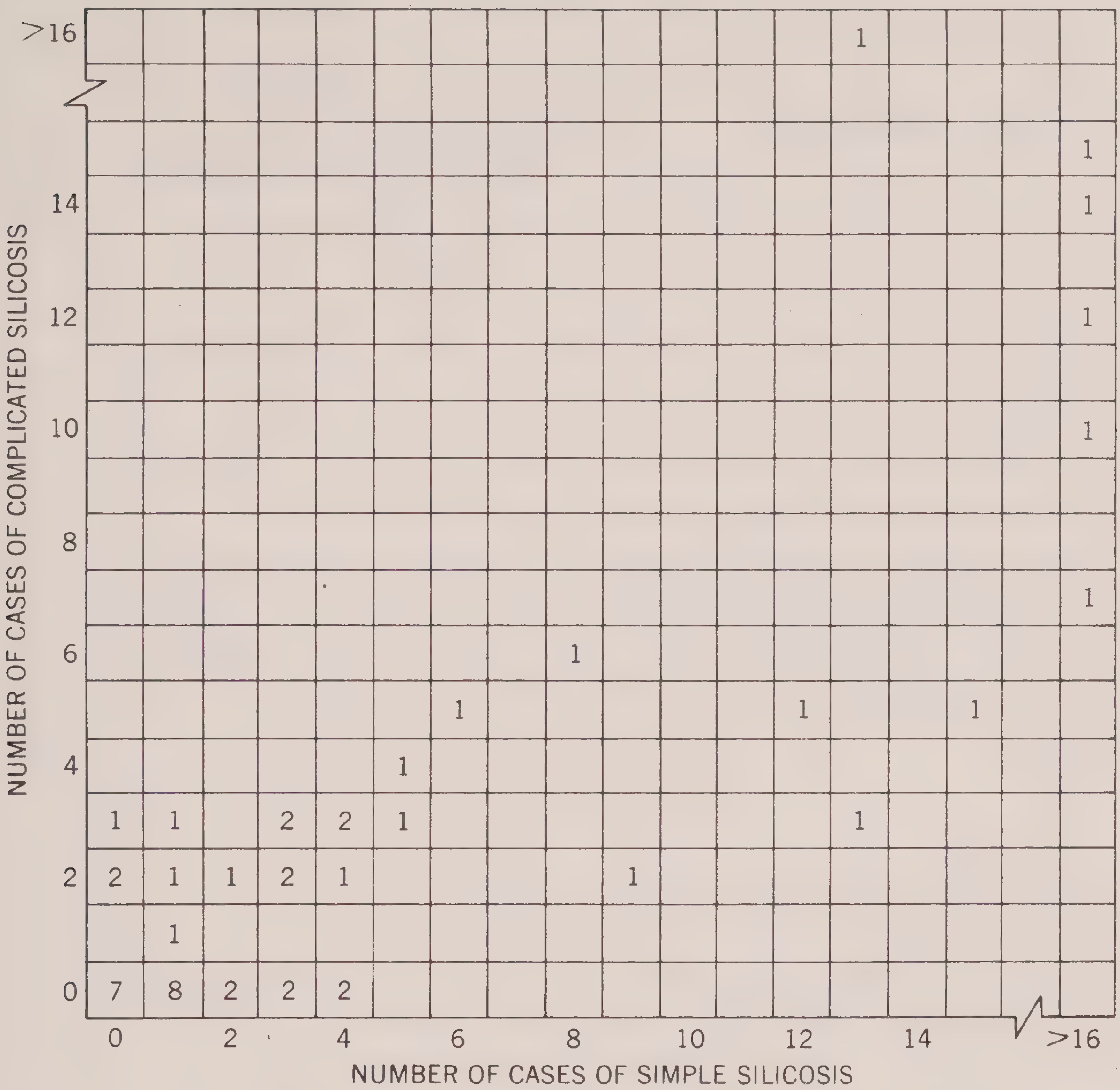

FIGURE V.5.—Frequency distribution of 50 metal mines showing number of cases of simple and complicated silicosis.

same. For example, in this table the mines do not remain in the same position with regard to the relative silicosis hazard when silicosis prevalence for all employees is compared with the silicosis prevalence limited to men with 10 years or more of metal mining experience. One mine with a large proportion of short-time miners had an overall silicosis rate of 4.0 percent, yet for men with 10 years or over in metal mining the silicosis rate rose to 18.7 percent, much above the average.

Table V.8, summarizing table V.7, shows a frequency distribution of metal mines by size according to the percent of workers with silicosis at each of the 50 mines. In each of the five silicosis prevalence groups there were one or more mines in the various size groups, except there were no large mines among those with 7.0 percent and over of silicotic workers. Thirteen mines had less than 1 percent of their employees affected with silicosis; 12 mines—1.0–2.9 percent; 13 mines—3.0–4.9 percent; 7 mines—5.0–6.9 percent; 5 mines—7 percent and over.

TABLE V.8.—*Frequency distribution of metal mines* by size showing percent of workers with silicosis*

Percent of workers with silicosis	Total number of mines	Number of mines by size			
		Less than 100 employees	100–299 employeees	300–699 employees	700 or more employees
0–0.9	13	2	6	2	3
1.0–2.9	12	2	6	2	2
3.0–4.9	13	3	6	1	3
5.0–6.9	7	2	1	3	1
7.0 and over	5	2	2	1	0

*Excludes uranium mine workers.

In considering the prevalence of silicosis among metal mine workers with 10 years or more of exposure, 8 of the 50 metal mines studied showed no cases of silicosis. There were 17 mines which had a silicosis prevalence of less than 5 percent, 12 mines had 5.0 to 9.9 percent silicosis, 9 mines had 10.0 to 14.9 percent silicosis, and 4 mines had from 18 to 20 percent with silicosis in these exposure groups.

The crude rate for all silicosis cases, both simple and complicated, showed little difference according to size of mine. It ranged from 3.3 percent for mines with 100–299 employees to 4.2 percent at mines with less than 100 employees. There was a slightly greater variation with size when consideration was limited to silicosis prevalence among workers with 10 or more years of metal mine experience. Mines with 100–299 employees showed a silicosis rate of 5.3 percent and mines with less than 100 employees showed 8.2 percent. On the other hand, mines with 300–699 employees and mines with 700 or more employees had silicosis rates of 5.5 and 6.5 percent, respectively.

History of Past Illnesses

Chest Illnesses

Table V.9 shows the history of past illnesses reported by each miner in reply to specific questions asked by the examining physician obtaining the medical history. The frequency of these illnesses is shown both by broad age groupings as well as broad groupings by years of employment in the metal mining industries.

A history of pneumonia was reported rather frequently in all age groups (14 to 40 percent) and showed a regular increase with increasing age and but little increase with years of mining employment. It did not seem appreciably higher in the silicotic groupings than the groups with normal* chest films.

*The term "normal" in this section implies no radiologic evidence of silicosis.

A history of pleurisy was reported less frequently than pneumonia in the nonsilicotic mining group and showed little difference with increasing age after 35 years of age and increasing length of employment, ranging from 5.1 to 15.2 percent. Among the workers showing evidence of silicosis, however, pleurisy was reported much more frequently (11.5 to 43.5 percent) but showed no regular rising trend with age and length of employment.

A medical history of bronchitis was reported in a low proportion of all miners in the large nonsilicotic group, the rates ranging from 4.1 to 9.3 percent, and with only a slight indication of an increasing prevalence with age and years of employment. It was reported only slightly more often in some of the silicotic groupings particularly among the younger silicosis cases.

A history of asthma was reported in a consistently small proportion of all age and length of employment groups, ranging from 2.1 to 7.8 percent, and increasing only slightly with age. It was only slightly more prevalent in the silicosis group and was not a common complaint.

Tuberculosis

A history of tuberculosis was reported infrequently by this mining population. In the large nonsilicotic group shown in table V.9, the rates were consistently well below 1.0 percent for miners below 45 years of age (0.2 to 0.5 percent). Above this age, the rates were slightly higher but reached only 1.1 percent. Because of the small numbers, the percentage rates fluctuated in the silicotic age groups, but the total cases reported were 14 out of 426 cases, or 3.3 percent, and ranged from 0 to 6.1 percent in the older age groupings.

A review of these case records of the metal mine workers reporting a previous history of tuberculosis and a check against their chest film interpretations showed that a substantial proportion of cases had no definite evidence of pulmonary tuberculosis. Out of 65 case histories of tuberculosis among the nonsilicotics only 13 were found to have definite findings of a previous infection. Similarly out of 14 silicosis cases with a history of tuberculosis only 5 showed definite evidence of past infection. The remainder of the cases had ill-defined and vague histories and no present X-ray evidence of past infection.

The above figures were based on miners giving a past history of tuberculosis. A more basic question is the actual prevalence of pulmonary tuberculosis as observed on the chest roentgenograms. As described previously, each film was read independently by the three radiological consultants who, in addition to classifying the film by the I.L.O. Classification of the Pneumoconioses, also added symbols and comments signifying the presence of other abnormalities in the

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TABLE V.9.—*Percent of workers at 50 metal mines* with certain present symptoms and past illnesses for silicotic and nonsilicotic workers by age and years worked at metal mines*

	Number									
	Age in years									
	Under 35		35–44		45–54			55 and over		
	Years at metal mines									
	−10	10+	−20	20+	−20	20–29	30+	−20	20–29	30+
	Workers without silicosis									
Past history:										
Pneumonia	538	93	644	92	386	210	84	95	89	154
Pleurisy	178	68	339	68	199	145	43	42	49	79
Bronchitis	153	27	175	26	110	62	29	24	35	35
Asthma	92	15	122	23	80	48	14	21	19	40
Tuberculosis	17	2	16	1	9	10	2	4	3	1
Heart trouble	65	14	75	14	68	36	17	26	25	57
Rheumatic fever	93	14	41	10	27	16	4	3	2	7
Rheumatism	105	35	256	57	251	151	51	70	86	134
Dust in lungs	27	12	82	24	65	93	25	14	34	40
Present symptoms:										
Chest wheezes:										
With colds	724	146	757	99	422	247	67	87	85	140
At other times	196	40	274	50	183	133	42	28	46	88
Chest illness in past 3 years	738	127	666	91	286	200	61	49	68	114
Short of breath	137	28	218	35	194	107	49	60	69	119
Number examined	3, 482	654	3, 130	448	1, 665	1, 024	311	375	381	591

	Workers with silicosis									
Past history:										
Pneumonia	-	-	5	3	12	22	18	3	17	33
Pleurisy	-	-	3	10	9	22	8	3	8	19
Bronchitis	-	-	3	3	6	9	1	1	3	9
Asthma	-	-	2	1	1	5	2	1	0	10
Tuberculosis	-	-	0	0	1	5	1	0	3	4
Heart trouble	-	-	0	2	1	1	6	0	5	7
Rheumatic fever	-	-	0	0	1	1	2	0	1	2
Rheumatism	-	-	5	5	9	19	4	7	9	36
Dust in lungs	-	-	13	10	14	41	19	7	19	59
Present symptoms:										
Chest wheezes:										
With colds	-	-	5	5	13	29	10	5	11	30
At other times	-	-	3	3	7	11	10	1	6	27
Chest illness in past 3 years	-	-	4	4	8	18	16	2	9	27
Short of breath	-	-	6	2	11	26	3	5	17	49
Number examined	-	-	26	23	48	91	45	15	49	129

*See footnote at end of table.

TABLE V.9.—*Percent of workers at 50 metal mines* with certain present symptoms and past illnesses for silicotic and nonsilicotic workers by age and years worked at metal mines*—Continued

	Percent									
	Age in years									
	Under 35		35–44		45–54			55 and over		
	Years at metal mines									
	–10	10+	–20	20+	–20	20–29	30+	–20	20–29	30+
	Workers without silicosis									
Past history:										
Pneumonia	15. 4	14. 2	20. 6	20. 5	23. 2	20. 5	27. 0	25. 3	23. 4	26. 1
Pleurisy	5. 1	10. 4	10. 8	15. 2	12. 0	14. 2	13. 8	11. 2	12. 9	13. 4
Bronchitis	4. 4	4. 1	5. 6	5. 8	6. 6	6. 1	9. 3	6. 4	9. 2	5. 9
Asthma	2. 6	2. 3	3. 9	5. 1	4. 8	4. 7	4. 5	5. 6	5. 0	6. 8
Tuberculosis	. 5	. 3	. 5	. 2	. 5	1. 0	. 6	1. 1	. 8	. 2
Heart trouble	1. 9	2. 1	2. 4	3. 1	4. 1	3. 5	5. 5	6. 9	6. 6	9. 6
Rheumatic fever	2. 7	2. 1	1. 3	2. 2	1. 6	1. 6	1. 3	. 8	. 5	1. 2
Rheumatism	3. 0	5. 4	8. 2	12. 7	15. 1	14. 7	16. 4	18. 7	22. 6	22. 7
Dust in lungs	. 8	1. 8	2. 6	5. 4	3. 9	9. 1	8. 0	3. 7	8. 9	6. 8
Present symptoms:										
Chest wheezes:										
With colds	20. 8	22. 3	24. 2	22. 1	25. 3	24. 1	21. 5	23. 2	22. 3	23. 7
At other times	5. 6	6. 1	8. 8	11. 2	11. 0	13. 0	13. 5	7. 5	12. 1	14. 9
Chest illness in past 3 years	21. 2	19. 4	21. 3	20. 3	17. 2	19. 5	19. 6	13. 1	17. 9	19. 3
Short of breath	3. 9	4. 3	7. 0	7. 8	11. 7	10. 4	15. 8	16. 0	18. 1	20. 1

	Workers with silicosis									
Past history:										
Pneumonia	--------	--------	19. 2	13. 0	25. 0	24. 2	40. 0	20. 0	34. 7	25. 6
Pleurisy	--------	--------	11. 5	43. 5	18. 7	24. 2	17. 8	20. 0	16. 3	14. 7
Bronchitis	--------	--------	11. 5	13. 0	12. 5	9. 9	2. 2	6. 7	6. 1	7. 0
Asthma	--------	--------	7. 7	4. 3	2. 1	5. 5	4. 4	6. 7	0	7. 8
Tuberculosis	--------	--------	0	0	2. 1	5. 5	2. 2	0	6. 1	3. 1
Heart trouble	--------	--------	0	8. 7	2. 1	1. 1	13. 3	0	10. 2	5. 4
Rheumatic fever	--------	--------	0	0	2. 1	1. 1	4. 4	0	2. 0	1. 6
Rheumatism	--------	--------	19. 2	21. 7	18. 7	20. 9	8. 9	46. 7	18. 4	27. 9
Dust in lungs	--------	--------	50. 0	43. 5	29. 2	45. 1	42. 2	46. 7	38. 8	45. 7
Present symptoms:										
Chest wheezes:										
With colds	--------	--------	19. 2	21. 7	27. 1	31. 9	22. 2	33. 3	22. 4	23. 3
At other times	--------	--------	11. 5	13. 0	14. 6	12. 1	22. 2	6. 7	12. 2	20. 9
Chest illness in past 3 years	--------	--------	15. 4	17. 4	16. 7	19. 8	35. 6	13. 3	18. 4	20. 9
Short of breath	--------	--------	23. 1	8. 7	22. 9	28. 6	6. 7	33. 3	34. 7	38. 0

*Excludes uranium mine workers.

chest roentgenograms. Evidence of pulmonary tuberculosis was routinely noted excepting the healed primary complex or childhood type of tuberculosis (Ghon tubercle).

Evidence of pulmonary tuberculosis, usually considered inactive or arrested, was noted by at least 2 of the 3 radiologists in 82 of the 13,600 nonsilicotic films, a frequency of 0.6 percent. Using the same criteria, tuberculosis was noted in 25 of the 476 films showing evidence of silicosis, a prevalence of 5.3 percent. In the former group of films, nine cases also had a previous history of tuberculosis, while in the silicotic group two cases gave a positive history.

Heart Trouble

A history of "heart trouble" was closely related to age. In the nonsilicotic population, the percentage rates in the two younger age groups ranged from 1.9 to 3.1 percent. In the 45–54 year age group, the rates ranged from 3.5 to 5.5 percent and were slightly higher in the employees with the longest work histories. In the oldest age group, 55 years and over, more history of "heart trouble" was apparent with the rates ranging up to 9.6 percent. Longer employment also appeared to have a relationship in this older group. Within the silicotic groupings, the small number of cases made age and length of employment comparisons difficult. There did not seem to be any excessive complaint of heart trouble in this population, however, based on 22 affirmative answers out of 426 silicotic cases, or 5.2 percent. All except two cases occurred over the age of 45 years.

Rheumatic Fever

A history of rheumatic fever was also reported infrequently in this mining population but somewhat more frequently in the younger age groups, the highest rate being 2.7 percent. It was reported among 1.6 percent of the silicotic population.

Rheumatism

The question regarding a history of "rheumatism" elicited a frequent positive response in all age and employment groups among the nonsilicotic workers but increased from a rate of 3.4 percent for all men under 35 years of age to 8.7 percent in the 35–44 age group, 15.1 percent in the 45–54-year age group, and 21.5 percent in the 55-years-and-over age group. Within each broad age grouping there was a slight trend toward increasing prevalence with increasing mining experience. In the relatively small silicotic population, however, a

positive history was more prevalent in the three broad age groupings and showed little relationship to length of mining employment aside from age.

Dust on Lungs

The reply to the question as to whether a miner had ever been told he had "dust on his lungs" was answered negatively in well over 90 percent of most age and employment groupings among the large nonsilicotic population. Affirmative replies in these nonsilicotic groupings ranged from 0.8 to 8.9 percent, however, and showed an increasing prevalence both with increasing age and increasing years of employment.

Within the relatively small population actually found to have silicotic X-ray changes, however, 182 or 42.7 percent of the 426 workers with present X-ray evidence of silicosis stated that they had been so informed. This large proportion of affirmative replies in the silicotic group did not appear to be related to age or length of employment within this group.

History of Lead Poisoning

A past history of lead poisoning was reported by 82 metal mine workers. Further examination of the records of these men indicated that for 21, the lead poisoning episode had occurred at a time when they were not employed in metal mining. Tasks mentioned included spraying orchards, painting, making storage batteries, and welding and cleaning gasoline tanks.

The remaining 61 men had suffered from lead poisoning while employed at metal mines. This constituted a prevalence of 0.4 percent of workers at all mines. If only men working at mines which were producing lead when the present study was made are considered, there were found to be 26 men who reported having had lead poisoning at some time in their past experience. This represents a prevalence of 0.7 percent as contrasted with 14 percent of the Utah metal miners who reported a history of lead poisoning when surveyed in 1939. Among 254 Utah metal miners examined in 1958, just 1 man reported ever having had lead poisoning. If the 1939 rate had continued the expected number of men with lead poisoning would have been 36. The great decrease in percent of men affected can be attributed to many factors, among which might be a change in the proportion of lead ores mined (more sulfide and less carbonate ore, which is more likely to cause lead poisoning).

The following tabulation shows the year when the last attack of lead poisoning occurred among the men questioned in the survey.

Year of last lead poisoning	Number of men
Before 1935	7
1935–1944	11
1945–1954	22
1955 and later	10
Unknown date	11
Total	61

These figures indicate that, although lead poisoning among miners is becoming increasingly rare, there are still cases which have developed within the past few years. Almost two-thirds of the mines studied revealed no workers with a history of lead poisoning. Only four mines reported more than three cases. The greatest number occurring at any one mine was eight cases.

The majority of attacks of lead poisoning in recent years had occurred at the same mine where the miner was working at the time of the medical examination. Attacks in earlier years had usually taken place at a mine other than that at which the worker was currently employed.

History of Mercurial Poisoning

Mercurial poisoning was very rarely reported among this group of miners. There were 23 cases which could apparently be attributed to exposure in metal mining occupations. Among 309 employees at mercury mines, 7 or 2.3 percent said they had been affected at some time with mercurial poisoning. Only three of these men indicated that the attack occurred at the same mine where they were examined. The remaining 16 men were not presently working at a mercury mine but had done so at some time in the past. A number of these men gave the name of mines where a mercury hazard was known to have existed. One-half of the cases, where the date was known, had taken place since 1950 and only one case had occurred before 1935. Some men reported having lost all of their teeth and some referred to intestinal symptoms.

Three men, not included above, mentioned poisoning from the medicinal use of mercury salves.

Frequency of Present Symptoms

Chest Illness

Table V.9 also shows the frequency of present symptoms reported in reply to the questions asked in taking the medical histories (fig. V.1). Roughly 20 to 25 percent of those examined reported that their

chests sounded "wheezy or whistling" when they had colds. In the large nonsilicotic group shown in table V.9 these rates were remarkably constant as to age and years of employment and showed no appreciable trends with either factor. In the smaller group of employees with silicosis, the rates fluctuated slightly and were a trifle higher, but showed no age or length of employment trends.

When the above question was worded to elicit a reply restricted to the presence of "wheezy and whistling" chest sounds at other times not associated with colds, the frequency of this symptom in both the nonsilicotic group and workers with silicosis was greatly reduced. In the nonsilicotic group, the prevalence of this symptom increased somewhat with age and also length of employment at metal mines, ranging from 5.6 percent in the youngest age group with short mining experience to 14.9 percent in the oldest group with the longest mining experience. In the smaller silicotic groups, the symptom was reported only somewhat more frequently in comparable age and employment groupings (6.7 to 22.2 percent) and could not be called a prominent symptom.

Complaints of a temporarily disabling chest illness within the past 3 years was fairly frequent and was reported by about 20 percent of most age and length of employment groups in the large nonsilicotic population. No trend was observed except that it occurred slightly more frequently in the groups under 45 years of age. In the silicosis groupings, chest illness was reported a little more frequently with increasing age and length of employment, but there were surprisingly few differences between these groups and the groups of nonsilicotic miners.

Shortness of Breath

Shortness of breath is an uncommon complaint among healthy young adults, but is frequently observed among elderly persons, obese persons, and those with emphysema and heart disease. It is generally considered a common manifestation of silicosis, especially in advanced stages when emphysema is a frequent complication. Questions regarding shortness of breath were based on studies made by British observers in their extensive research studies of coal miners pneumoconiosis.

Table V.9 shows the frequency of complaints of some degree of shortness of breath by age and length of employment groupings. In the nonsilicotic population it was reported by less than 5 percent of the miners under 35 years of age. The prevalence of this complaint gradually increased with age and years of employment to about 20 percent in the older age groupings with long employment at metal mines. In the much smaller silicotic group, shortness of breath was

a much more common complaint in all age groups, ranging from an average rate of 16.3 percent for all men under 45 years of age and 21.7 percent for men 45 to 54 years of age to 36.8 percent for those of 55 years of age and over. Within these broad age groupings, there was no clear trend with length of employment, except that the highest rate, 38 percent, was found in the oldest group of men with 30 years or more of mining experience.

Earlier studies have shown that many industrial workers with early or moderate degrees of silicosis did not experience any remarkable subjective complaints of the disease. Consequently, in evaluating the symptoms of silicosis, they should be related to other findings such as the degree of changes in the chest roentgenogram.

Table V.10 and figure V.6 show the prevalence of shortness of breath with relation to the degree of silicosis and length of employment at the metal mines, and table V.11 shows shortness of breath related to the detailed X-ray categorization by age and also by years of employment at metal mines.

Table V.10 also shows that 1,141 out of 12,479 metal mine workers, or 9.1 percent, reported some degree of shortness of breath. Among the large population of 11,922 with no X-ray evidence of silicosis, the rates for this symptom increased from 5.8 percent to 20.4 percent with increasing years of mining employment. Among the rather small group of 133 workers with suspect or doubtful chest films, only 17, or 12.8 percent, reported this complaint.

With simple silicosis, however, 71 of the 271 workers so classified, or 26.2 percent, reported shortness of breath, and the percentage rates increased from 15.6 for those with less than 15 years employment to 38.5 percent for those with 35 or more years of employment. With more advanced or complicated silicosis, the symptom was reported by 55 out of 153 employees, or 35.9 percent. The rates increased from about 25 percent for those employed less than 25 years to over 40 percent for those employed more than 25 years. Hence, it will be observed that shortness of breath was reported about three to four times as frequently among the silicotic as the nonsilicotic miners and ranged somewhat higher among those with complicated silicosis with increasing years of employment.

Table V.11 shows the prevalence of shortness of breath reported according to the degree of change in the X-ray chest films as defined in the I.L.O. Radiological Classification of the Pneumoconioses, and also by broad age and length of exposure groupings. The prevalence of this symptom for all negative chest films was 8.4 percent and increased regularly from 18.6 percent for all category 1 films to 50 percent for the 56 films classified as categories B and C denoting the more advanced complicated silicosis cases. A similar trend in the prevalence of shortness of breath within the broad age groupings was

TABLE V.10.—*Shortness of breath among workers at 50 metal mines* according to lung field markings and years at metal mines*

Lung field markings	Years at metal mines				
	Total	−15	15–24	25–34	35+
	Number examined				
Total	†12, 479	7, 576	3, 161	1, 220	522
No abnormal markings	11, 922	7, 503	2, 973	1, 015	431
Doubtful	133	34	47	36	16
Simple silicosis	271	32	98	102	39
Complicated silicosis	153	7	43	67	36
	Number with shortness of breath				
Total	1, 141	444	373	203	121
No abnormal markings	998	432	331	147	88
Doubtful	17	5	3	6	3
Simple silicosis	71	5	28	23	15
Complicated silicosis	55	2	11	27	15
	Percent with shortness of breath				
Total	9. 1	5. 9	11. 8	16. 6	23. 2
No abnormal markings	8. 4	5. 8	11. 1	14. 5	20. 4
Doubtful	12. 8	14. 7	6. 4	16. 7	18. 8
Simple silicosis	26. 2	15. 6	28. 6	22. 5	38. 5
Complicated silicosis	35. 9	28. 6	25. 6	40. 3	41. 7

*Excludes uranium mine workers.
†Does not include 8 workers with no information on shortness of breath.

also observed by categories, and a somewhat less regular trend was shown by length of exposure groupings.

The question has been raised as to whether the responses to questions regarding shortness of breath show a relationship to the elevation at which men work and live.

The percent of workers with slight and moderate shortness of breath reported is shown according to elevation of the mine and living area in table V 12. The 50 metal mines were separated into 3 groups by elevation. Consideration was given both to the elevation at the entrance of the mine and at the surrounding areas where the workers lived. Broad groupings were possible in which each mine could be placed. Among the large group of men without silicosis working at less than 2,000 feet, slight shortness of breath was reported among

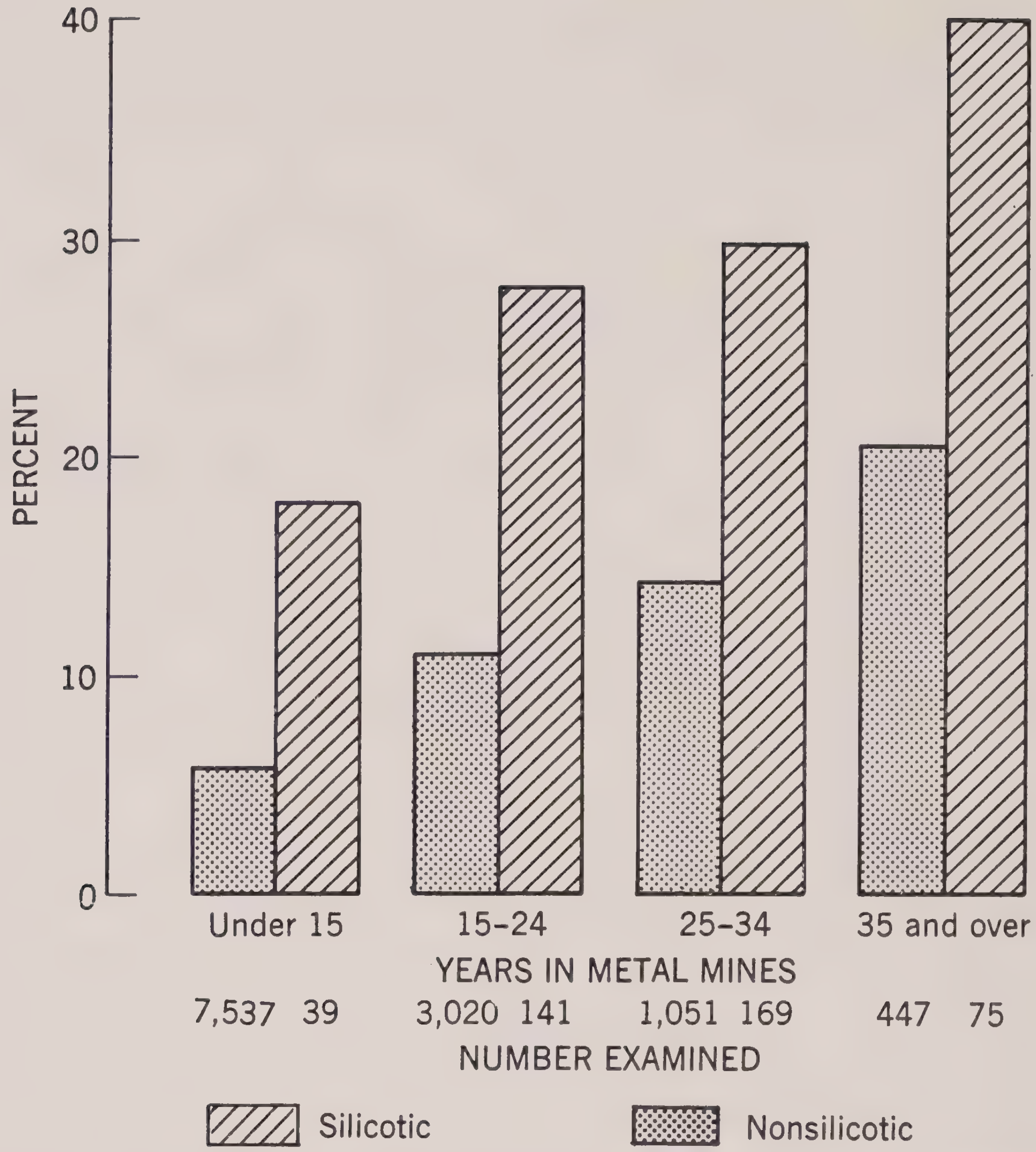

FIGURE V.6.—Shortness of breath among workers with and without silicosis according to years worked in 50 metal mines.

5.3 percent, moderate shortness of breath among 0.5 percent for those men less than 45 years of age, and 12.6 percent and 3.5 percent for men 45 years of age and over. Workers at 2,000–4,999 feet and at 5,000 feet and over showed a slightly lower percentage with slight and with moderate shortness of breath among both age groups. Workers with silicosis 45 years of age and over had approximately double the percentage with slight shortness of breath and more than three times the percentage with moderate shortness of breath as among normal workers. There was little difference in shortness of breath according to elevation. This may be partly accounted for by the fact that men working at higher elevations expected to have some degree of shortness of breath and did not consider this abnormal when it was no worse than their fellow workers.

TABLE V.11.—*Shortness of breath among workers at 50 metal mines* according to detailed lung field markings, age and years at metal mines*

Lung field markings	Age				Years at metal mines		
	Total	−45	45−54	55+	−25	25−34	35+
	Number examined						
Total	†12, 479	7, 760	3, 182	1, 537	10, 737	1, 220	522
No abnormal markings	11, 922	7, 681	2, 934	1, 307	10, 476	1, 015	431
Doubtful	133	30	64	39	81	36	16
Category 1	43	8	22	13	21	19	3
Category 2	186	26	87	73	92	68	26
Category 3	28	1	15	12	13	9	6
Eggshell	14	1	5	8	4	6	4
Category A	97	12	31	54	37	40	20
Category B	38	-------	14	24	7	17	14
Category C	18	1	10	7	6	10	2
	Number with shortness of breath						
Total	1, 141	426	398	317	817	203	121
No abnormal markings	998	416	341	241	763	147	88
Doubtful	17	2	9	6	8	6	3
Category 1	8	-------	5	3	5	2	1
Category 2	50	4	25	21	25	17	8
Category 3	12	-------	4	8	3	4	5
Eggshell	1	-------	-------	1	-------	-------	1
Category A	27	4	4	19	7	16	4
Category B	19	-------	5	14	3	6	10
Category C	9	-------	5	4	3	5	1
	Percent with shortness of breath						
Total	9. 1	5. 5	12. 5	20. 6	7. 6	16. 6	23. 2
No abnormal markings	8. 4	5. 4	11. 6	18. 4	7. 3	14. 5	20. 4
Doubtful	12. 8	6. 7	14. 1	15. 4	9. 9	16. 7	18. 8
Category 1	18. 6	-------	22. 7	23. 1	23. 8	10. 5	**33. 3
Category 2	26. 9	15. 4	28. 7	28. 8	27. 2	25. 0	30. 8
Category 3	42. 9	-------	26. 7	66. 7	23. 1	**44. 4	**83. 3
Eggshell	7. 1	-------	-------	**12. 5	-------	-------	**25. 0
Category A	27. 8	33. 3	12. 9	35. 2	18. 9	40. 0	20. 0
Category B	50. 0	-------	35. 7	58. 3	**42. 9	35. 3	71. 4
Category C	50. 0	-------	50. 0	**57. 1	**50. 0	50. 0	**50. 0

*Excludes uranium mine workers.

†Does not include 8 workers with no data on shortness of breath.

**Based on less than 10 employees in exposure group.

TABLE V.12.—*Shortness of breath among workers at 50 metal mines* according to elevation of mine and age, workers with or without silicosis*

Elevation	Less than 45 years of age				45 years of age and over			
	Number examined	Short of breath			Number examined	Short of breath		
		Number	Percent			Number	Percent	
			Slight	Moderate			Slight	Moderate
	Workers without silicosis							
Less than 2,000 feet	2, 056	120	5. 3	0. 5	1, 527	246	12. 6	3. 5
2,000–4,999 feet	2, 484	118	4. 3	. 5	1, 319	145	9. 0	2. 0
5,000 feet and over	3, 174	180	4. 8	. 9	1, 501	206	10. 8	2. 9
	Workers with silicosis							
Less than 2,000 feet	1	-----	------	------	37	12	21. 6	10. 8
2,000–4,999 feet	28	2	3. 6	3. 6	184	52	20. 1	8. 2
5,000 feet and over	20	6	15. 0	15. 0	156	53	22. 5	11. 5

*Excludes uranium mine workers.

Silicosis Related to Type and Duration of Exposure

Years in Metal Mining

As has been found in previous industrial studies of silicosis, the prevalence of silicosis increased rapidly with increasing years of work within the metal mining industry. Table V.13 shows the increasing rate of prevalence in increments of 5-year work exposures. The large mining population involved in this survey permits a 5-year breakdown into 10 groupings ranging from less than 5 years of exposure to 45 years and over.

The following observations may be made from table V.13:

1. No cases occurred with less than 5 years of exposure.
2. Seven cases (0.2 percent) occurred in workers with 5–9 years of exposure.
3. After 10 years or more of exposure the prevalence rates rose rapidly in 5-year increments from 1.4, 3.0, 7.6, and 12.1 percent up to an average rate of 16.6 percent for the four exposure groups shown as working 30, 35, 40, and 45 years and over. The variation in the rates in these four longest working groups is attributed to the smaller population at risk and the sizable proportion of older men in these groups working at mines offering relatively low free silica exposures.

Taking the chest X-ray film.

Table V.13 also shows that the proportion of complicated to simple silicosis cases tended to increase in the groups with increasing duration of exposure.

Age of Workers

Although the miners' age and their years of employment in the metal mining industry have a close relationship, it is of interest to note the prevalence of silicosis in this mining population by age categories. Table V.14 and figure V.7 show the increasing prevalence of silicosis

TABLE V.13.—*Number and percent of metal mine workers* with X-ray evidence of silicosis according to years at metal mines*

Years at metal mines	Number examined	Silicosis—number			Silicosis—percent		
		Total	Simple	Complicated	Total	Simple	Complicated
Total	14, 076	476	305	171	3. 4	2. 2	1. 2
Less than 5 years	3, 530	------	------	------	------	------	------
5–9	2, 986	7	7	------	. 2	. 2	------
10–14	2, 397	35	27	8	1. 4	1. 1	. 3
15–19	1, 927	58	47	11	3. 0	2. 4	. 6
20–24	1, 416	107	69	38	7. 6	4. 9	2. 7
25–29	709	86	50	36	12. 1	7. 1	5. 0
30–34	578	105	65	40	18. 2	11. 3	6. 9
35–39	346	51	28	23	14. 8	8. 1	6. 7
40–44	156	21	9	12	13. 5	5. 8	7. 7
45 and over	31	6	3	3	19. 4	9. 7	9. 7

*Includes uranium miners.

TABLE V.14.—*Number and percent of metal mine workers* with X-ray evidence of silicosis according to age*

Age in years	Number examined	Silicosis—number			Silicosis—percent		
		Total	Simple	Complicated	Total	Simple	Complicated
Total	14, 076	476	305	171	3. 4	2. 2	1. 2
Less than 20	155	------	------	------	------	------	------
20–24	1, 140	------	------	------	------	------	------
25–29	1, 652	------	------	------	------	------	------
30–34	2, 046	------	------	------	------	------	------
35–39	1, 951	7	5	2	. 4	. 3	. 1
40–44	2, 042	50	38	12	2. 4	1. 9	. 5
45–49	1, 912	81	53	28	4. 2	2. 8	1. 4
50–54	1, 550	134	94	40	8. 6	6. 1	2. 5
55–59	1, 000	115	68	47	11. 5	6. 8	4. 7
60–64	565	69	40	29	12. 2	7. 1	5. 1
65 and over	63	20	7	13	31. 7	11. 1	20. 6

*Includes uranium miners.

with increasing age, in increments of 5 years, and ranging from less than 20 years of age to over 65 years of age.

Silicosis was not observed in chest films of miners of less than 35 years of age, and only 7 cases or 0.4 percent were found among the 1,951 workers in the 35–39-year age grouping. Beginning with the 40–44-year age group with a prevalence rate of 2.4 percent, there was

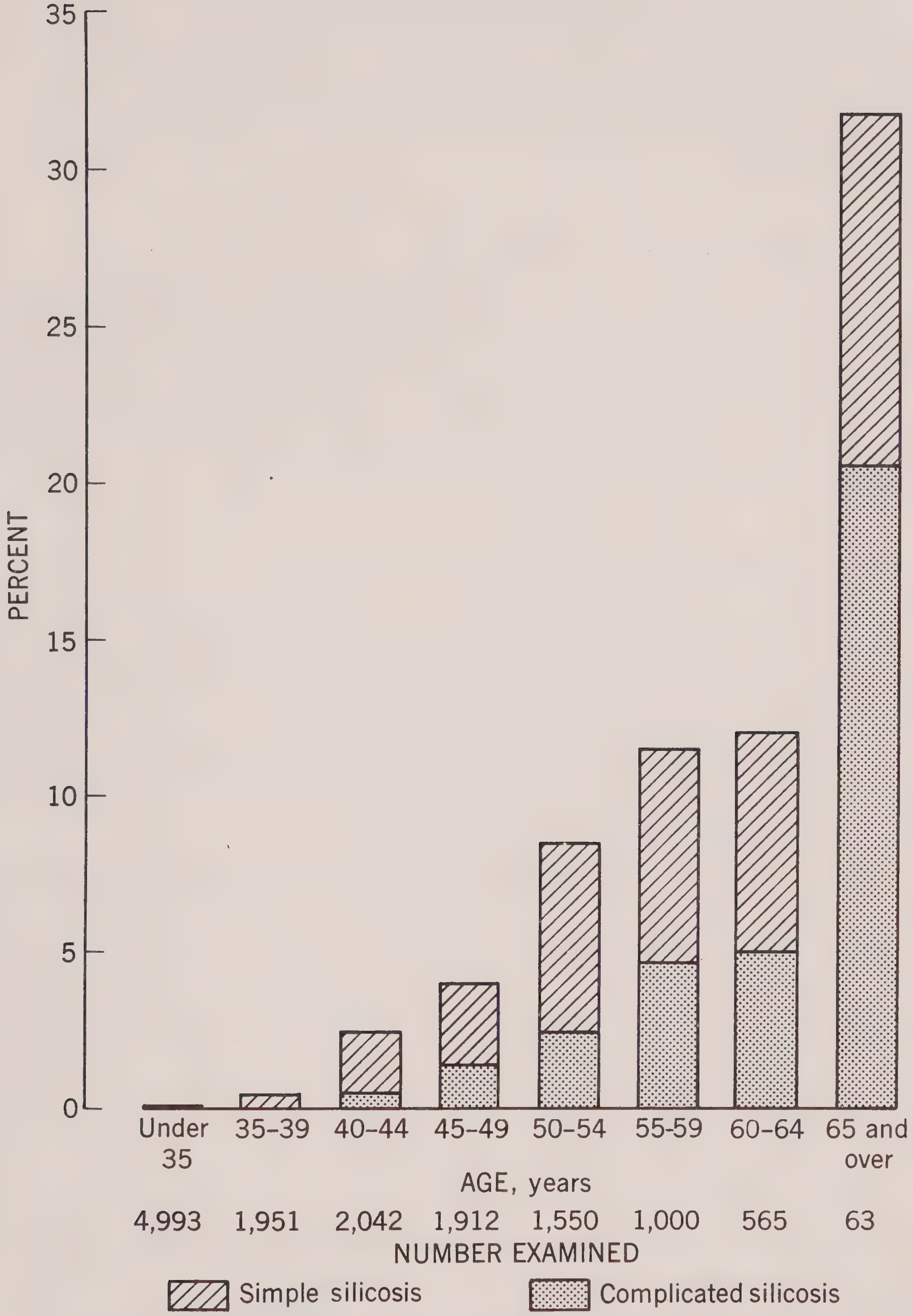

FIGURE V.7.—Percent of all metal mine workers with silicosis by age.

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a moderate increase in the rate for positive cases with each succeeding age group until it tended to level off at about 12 percent in the 55–59- and 60–64-year age groups. The 63 men examined who were in the 65-year-and-over age group included 20 cases of silicosis, or 31.7 percent. Of these 20 cases, 13 or two-thirds were classified as complicated silicosis.

Age and Years in Metal Mining

Table V.15 and figure V.8 show the prevalence of silicosis both by 10-year age groupings and by the years of mining employment. Within the three oldest broad age groupings beginning with the age of 40–49 years, it will be seen that the prevalence rates for silicosis rose sharply within these age groups with increasing years of employment, but in no instance quite reaching 20 percent.

Years in Metal Mining and Principal Occupation

It has been shown that there is a close correlation between the number of years worked at metal mines and the prevalence of silicosis. It is of particular interest from the viewpoint of evaluating and controlling the silicosis problem to determine what occupations may have been largely responsible for causing the disease and their relative importance, in pointing out the need for further control measures in reducing the exposure to silicious dust.

Table V.16 shows the prevalence of silicosis among the employees of 50 metal mines by years of employment at metal mines and by broad categories of principal occupation.* Of the 426 workers with silicosis, 344 or 80.8 percent had been employed principally underground, 62, or 14.5 percent had been employed on the surface, and 20 or 4.7 percent had no principal occupation. The overall prevalence rate for all 8,435 underground workers was 4.1 percent, and for the 2,870 surface workers, 2.2 percent.

For underground workers, the prevalence rates ranged from 2.0 percent for transportation workers, 2.2 percent for maintenance and construction workers, 3.9 percent for miscellaneous workers, and up to 5.0 percent for the large group of faceworkers.

For surface workers, the prevalence rates for silicosis ranged from less than 1 percent (0.7) for both transportation workers and miscellaneous workers up to 3.5 percent for millworkers at the dustiest surface operation.

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*Principal occupation refers to work performed during more than half the time spent in metal mining, except miners working 10 years or more at the face are classified as faceworkers.

TABLE V.15.—*Number and percent of metal mine workers* with X-ray evidence of silicosis according to age and years at metal mines*

Age in years	Years at metal mines: Total	Less than 10 years	10–19 years	20–29 years	30–39 years	40 years and over
	Total examined					
Total	14, 076	6, 516	4, 324	2, 125	924	187
Less than 20	155	155				
20–29	2, 792	2, 714	78			
30–39	3, 997	2, 284	1, 671	42		
40–49	3, 954	999	1, 778	1, 126	51	
50–59	2, 550	325	696	801	667	61
60 or over	628	39	101	156	206	126
	Number with silicosis					
Total	476	7	93	193	156	27
Less than 20						
20–29						
30–39	7		6	1		
40–49	131	4	42	77	8	
50–59	249	3	40	95	107	4
60 or over	89		5	20	41	23
	Percent with silicosis					
Total	3. 4	0. 1	2. 2	9. 1	16. 9	14. 4
Less than 20						
20–29						
30–39	. 2		. 4	2. 4		
40–49	3. 3	. 4	2. 4	6. 8	15. 7	
50–59	9. 8	. 9	5. 7	11. 9	16. 0	6. 6
60 or over	14. 2		5. 0	12. 8	19. 9	18. 3

*Includes uranium miners.

By far the most important group of occupations with reference to the silicosis problem are those included in the category "face-workers," who were engaged in mining production and development operations. Silicosis occurred in 267 or 5.0 percent of the 5,330 face-workers. These 267 cases comprised 62.5 percent or well over half of the 426 cases of silicosis found among the 12,487 workers at these 50 metal mines. Among the 5,330 faceworkers, silicosis began appearing after 10 years of employment and increased to 10.7 percent

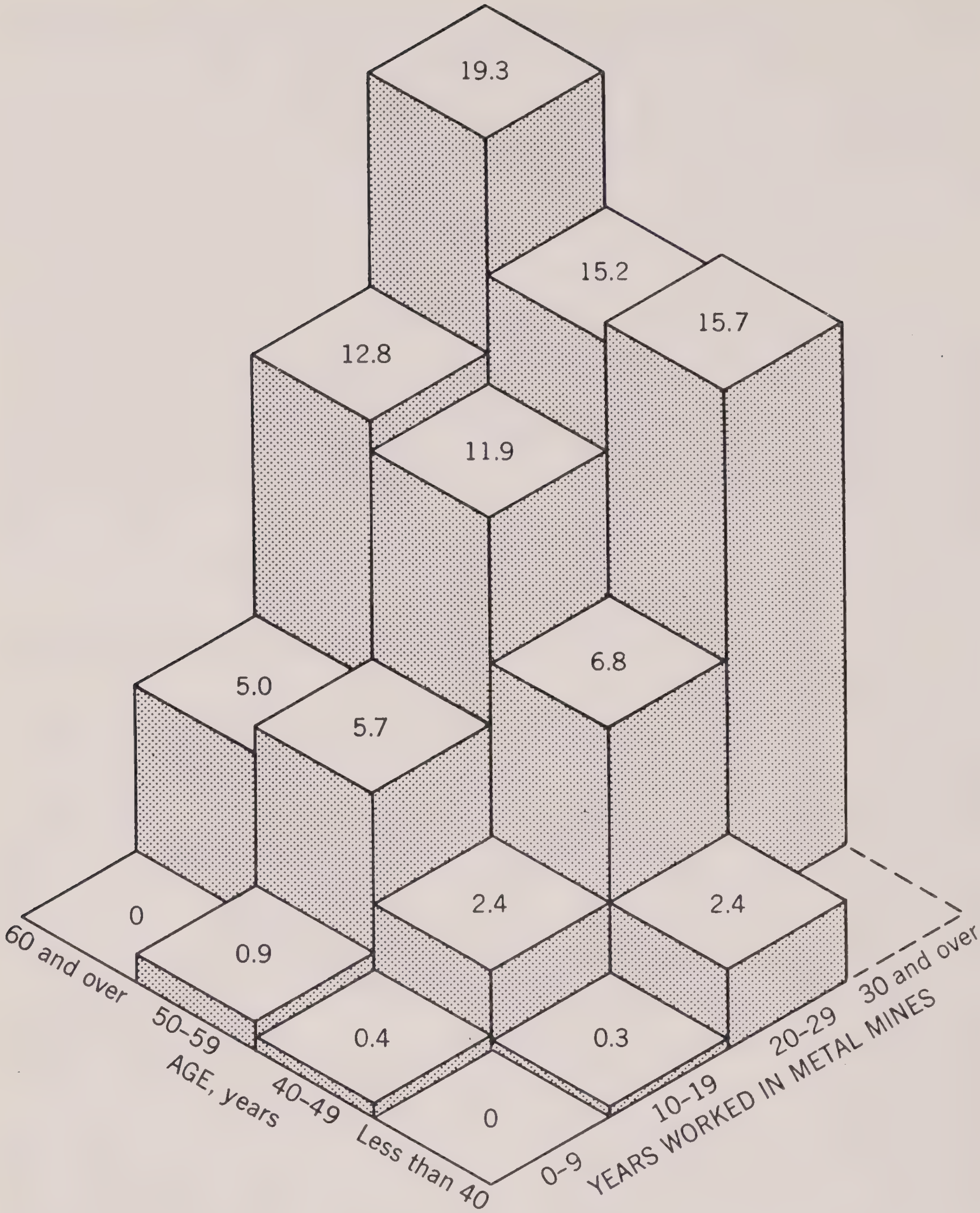

FIGURE V.8.—Percent of metal mine workers with silicosis according to age and years worked in metal mines.

of the men in the 20–29-years-of-employment grouping, and on upward to 26.1 percent of the 463 faceworkers with 30 or more years of employment. Similar trends, but on smaller scale, were seen in several other groups of principal occupations.

It soon became evident in analyzing these data that certain considerations were obscuring the general picture of prevalence of silicosis in treating the metal mines as a whole. Seven iron and lead-

TABLE V.16.—*Percent of workers with evidence of silicosis at 50 metal mines* according to principal occupation and years at metal mines*

Principal occupation	Total			Less than 10 years			10–19 years			20–29 years			30 years and over		
	Number		Percent	Number		Percent	Number		Percent	Number		Percent	Number		Percent
	Examined	Silicosis		Examined	Silicosis		Examined	Silicosis		Examined	Silicosis		Examined	Silicosis	
Total	12, 487	426	3. 4	5, 411	7	0. 1	3, 983	82	2. 1	2, 016	163	8. 1	1, 077	174	16. 2
Underground total	8, 435	344	4. 1	3, 547	4	. 1	2, 802	65	2. 3	1, 381	132	9. 6	705	143	20. 3
Face	5, 330	267	5. 0	2, 089	2	. 1	1, 874	47	2. 5	904	97	10. 7	463	121	26. 1
Transportation	1, 265	25	2. 0	612	----	-----	394	7	1. 8	176	9	5. 1	83	9	10. 8
Maintenance and construction	1, 171	26	2. 2	569	2	. 4	348	9	2. 6	173	11	6. 4	81	4	4. 9
Miscellaneous	669	26	3. 9	277	----	-----	186	2	1. 1	128	15	11. 7	78	9	11. 5
Surface total	2, 870	62	2. 2	1, 148	3	. 3	915	14	1. 5	488	25	5. 1	319	20	6. 3
Transportation	307	2	. 7	116	----	-----	113	1	. 9	50	1	2. 0	28	-----	-----
Maintenance and construction	1, 074	28	2. 6	392	----	-----	342	2	. 6	192	14	7. 3	148	12	8. 1
Mill	777	27	3. 5	370	3	. 8	253	10	4. 0	106	9	8. 5	48	5	10. 4
Miscellaneous	712	5	. 7	270	----	-----	207	1	. 5	140	1	. 7	95	3	3. 2
No principal	1, 182	20	1. 7	716	----	-----	266	3	1. 1	147	6	4. 1	53	11	20. 8

*Excludes uranium mine workers.

zinc mines located in low free silica limestone formations which had fairly large and stable populations offered low exposures to free silica in their mining operations. It was found that there was very little silicosis at these mines even among the sizable groups of older workers that had been employed 25 or 30 years or longer. If these groups were considered separately, a consistent trend was found among the remaining 43 mines that did offer a more substantial exposure to free silica in their mining operations.

Table V.17 and figure V.9 show the prevalence rates for silicosis by principal occupation; however, 7 of the 50 mines employing 2,201 workers are excluded from this analysis. These seven mines which were located in low free silica limestone formations included a large group of longtime employees who did not have silicosis, hence they tend to distort the total figures showing progressive increase in percent silicosis with increasing years of metal mine employment. The remaining group of 10,286 men, none of whom worked at mines located in low free silica limestone formations, were subdivided into 5-year work intervals and the silicosis rates were calculated for each principal occupation.

When rates were examined without regard to years in metal mining, faceworkers had the most silicosis with 5.9 percent, followed by miscellaneous underground workers, 4.7 percent; millworkers, 4.2 percent; maintenance and construction workers—surface, 3.1 percent; maintenance and construction workers—underground, 2.8 percent; underground transportation workers, 2.3 percent; miscellaneous surface workers, 1.0 percent; and surface transportation workers, 0.8 percent. Silicotic faceworkers constituted 62.7 percent of all silicotic workers, while the remaining persons with silicosis were distributed over a number of different underground and surface occupations. However, when considered according to years worked in metal mining, some of the occupations with small numbers of workers showed a prevvalence rate of silicosis higher than that found among the large group of faceworkers. The higher silicosis prevalence for nonface workers was observed in certain length of exposure groups among surface millworkers and miscellaneous underground workers.

The tendency for silicosis prevalence to increase with increasing years of work in metal mining was noted among all occupational groups at these 43 mines, but it was more steadily upward and reached a higher peak, 38.9 percent, among faceworkers. The next most steady increase was for underground transportation workers, who showed 26.3 percent with silicosis after 35 years or over in metal mining. Surface occupations, in general, failed to show as regular a rise in the percent with silicosis.

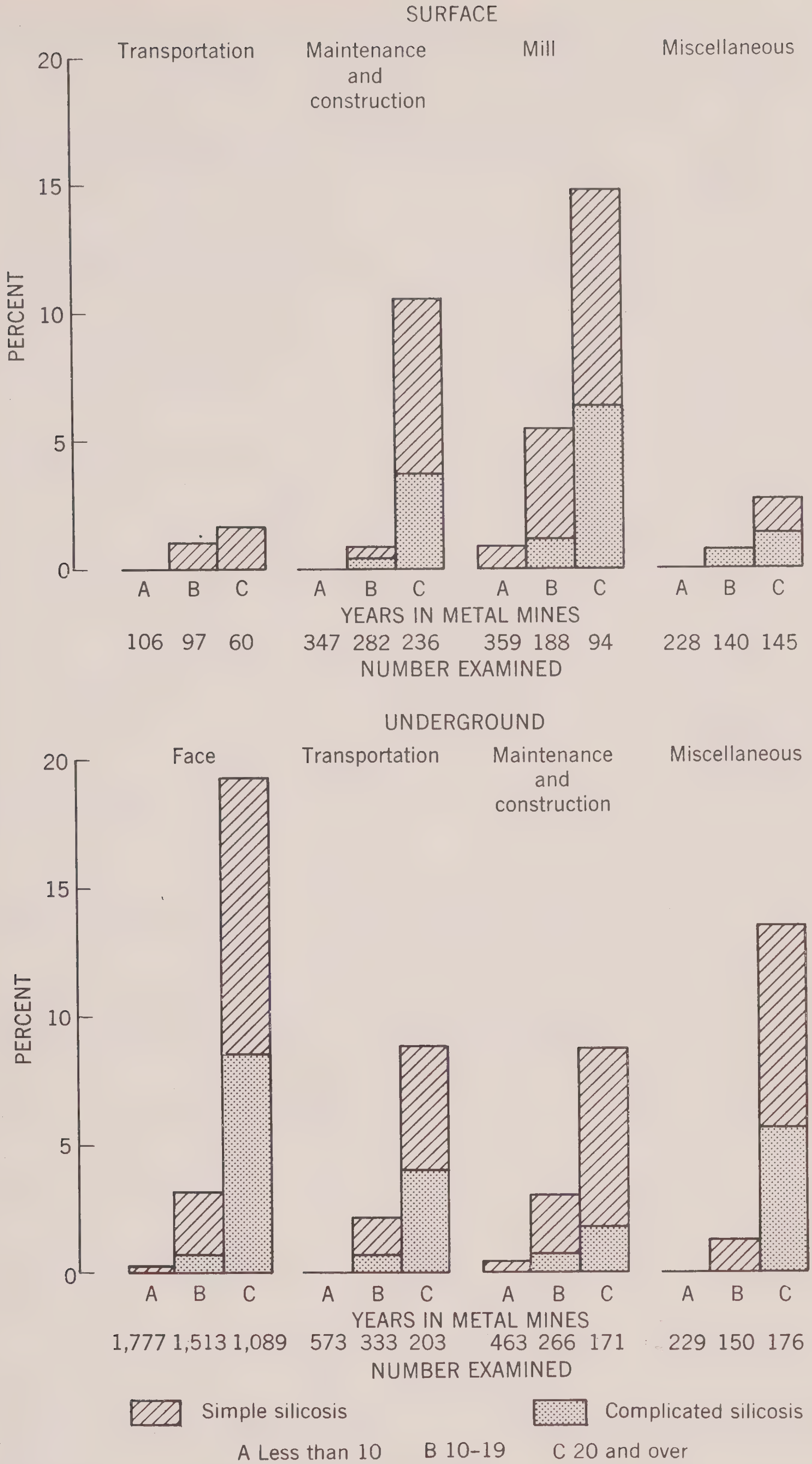

FIGURE V.9.—Percent of metal mine workers with silicosis acording to principal occupation and years worked in metal mines. (Excludes seven iron and lead-zinc mines in low free silica limestone formations.)

TABLE V.17.—*Silicosis among metal mine workers* by principal occupation and years at metal mines*

Years at metal mines	Total	Underground: Face	Underground: Transportation	Underground: Maintenance and construction	Underground: Miscellaneous	Surface: Transportation	Surface: Maintenance and construction	Surface: Mill	Surface: Miscellaneous	No principal
Number examined										
Total	10, 286	4, 379	1, 109	900	555	263	865	641	513	1, 061
0–5	2, 423	714	305	238	133	41	146	193	104	549
5–9	2, 347	1, 063	268	225	96	65	201	166	124	139
10–14	1, 884	934	182	145	79	55	171	107	81	130
15–19	1, 304	579	151	121	71	42	111	81	59	89
20–24	1, 027	490	95	78	73	25	86	46	58	76
25–29	563	255	54	41	39	15	58	27	35	39
30–34	444	218	35	32	42	9	45	13	26	24
35 and over	294	126	19	20	22	11	47	8	26	15
Number with silicosis										
Total	415	260	25	25	26	2	27	27	5	18
0–5	—	—	—	—	—	—	—	—	—	—
5–9	7	2	—	2	—	—	—	3	—	—
10–14	31	19	2	3	1	1	—	4	—	1
15–19	49	27	5	5	1	—	2	6	1	2
20–24	91	60	3	6	5	—	8	7	—	2
25–29	70	36	6	5	10	1	6	2	1	3
30–34	95	67	4	1	6	—	6	3	2	6
35 and over	72	49	5	3	3	—	5	2	1	4

	Percent with silicosis									
Total	4. 0	5. 9	2. 3	2. 8	4. 7	0. 8	3. 1	4. 2	1. 0	1. 7
0–5										
5–9	. 3	. 2		. 9				1. 8		
10–14	1. 6	2. 0	1. 1	2. 1	1. 3	1. 8		3. 7		. 8
15–19	3. 8	4. 7	3. 3	4. 1	1. 4		1. 8	7. 4	1. 7	2. 2
20–24	8. 9	12. 2	3. 2	7. 7	6. 9		9. 3	15. 2		2. 6
25–29	12. 4	14. 1	11. 1	12. 2	25. 6	6. 7	10. 3	7. 4	2. 9	7. 7
30–34	21. 4	30. 7	11. 4	3. 1	14. 3		13. 3	23. 1	7. 7	25. 0
35 and over	24. 5	38. 9	26. 3	15. 0	13. 6		10. 6	25. 0	3. 8	26. 7

*Excludes uranium mines and 7 iron and lead-zinc mines in low free silica limestone formations.

Present Occupation

Table V.18 shows in detail the present occupation of all workers and of workers with silicosis. From this table it was possible to learn the number of workers engaged in a variety of occupations at the mines studied at the time of the medical examinations. Thus, among the 4,474 men who were working at the face, 3,066 were stope miners, 686 were drift miners, 449 were raise miners, and 273 were performing other work at the face. Underground transportation consisted chiefly of motor crews but there were also 265 underground hoisting operators, 177 skip tenders and chute pullers, 94 mobile equipment operators, and 32 grizzlymen. The two principal groups of underground maintenance and construction workers were timbermen and mechanics and pipemen. Miscellaneous underground workers were primarily supervisors and engineers.

A classification of workers by present occupation tells only what a man was doing at the time he was examined and does not indicate how long he had been engaged in that particular job. However, it is of interest to observe where persons with silicosis were found at the time they were examined. There were 269 persons with simple or complicated silicosis who were presently employed underground and 98 of these were working at the face. On the surface, there were found to be 157 persons with silicosis. The great majority of these had previously had years of underground working exposure.

Present Occupation Compared With Principal Occupation

Table V.19 shows the present occupation of metal mine workers and indicates the principal occupation which each had followed during his entire mining experience. For example, among 4,474 men now working at the face, 3,883 had worked principally at that occupation, 161 men had spent most time in underground transportation, 52 had been chiefly in underground maintenance and construction, 72 had been in other underground work, 41 had worked on the surface, and 265 had not worked at any one job long enough to have a principal occupation. Although the largest group of workers was found under the same classification for principal as for present occupation, there were many other types of work formerly followed by substantial groups of persons.

The practice of transferring older and less physically fit workers from underground to surface jobs was reflected in the figures showing percent with silicosis by present and principal occupation. The highest silicosis rates for men whose principal occupation had been at the working face were found in men presently working on the surface, namely 22.1 percent with silicosis in maintenance and construction, 23.2 percent in surface millwork, and 21.0 percent at other

TABLE V.18.—*Workers at 50 metal mines* according to occupation at time of medical examination*

Present occupation	Number of workers	Number with silicosis
Grand total	12, 487	426
Underground—face—total	4, 474	98
Stope miner	3, 066	57
Drift miner	686	22
Raise miner	449	5
Other faceworkers	273	14
Underground—transportation—total	1, 468	33
Motor crew	900	17
Grizzlyman	32	--------
Underground hoisting operator	265	12
Skip tender and chute puller	177	3
Mobile equipment operator	94	1
Underground—maintenance and construction—total	1, 818	75
Timberman	505	38
Trackman	148	3
Electrician	185	4
Mechanic and pipeman	492	11
Other maintenance and construction workers	488	19
Underground—miscellaneous—total	1, 078	63
Supervisor	535	46
Powderman	43	5
Nipper	60	2
Engineer and sampler	201	4
General laborer	239	6
Surface—transportation—total	424	8
Hoistman	144	3
Topman	41	--------
Mobile equipment operator	239	5
Surface—maintenance and construction—total	1, 404	67
Electrican	181	2
Mechanic and pipeman	448	15
Carpenter	126	11
Bit repairman	19	1
Welder	136	2
General laborer	494	36
Surface—mill—total	898	38
Crusher worker	314	10
Other millworkers	584	28
Surface—miscellaneous—total	923	44
Office and general supervision	566	13
Assayer	110	2
Miscellaneous laborer	247	29

*Excludes uranium mine workers.

TABLE V.19.—*Present occupation compared with principal occupation of workers at 50 metal mines* according to percent with silicosis*

Principal occupation	Present occupation							
	Underground				Surface			
	Face	Transportation	Maintenance and construction	Other	Transportation	Maintenance and construction	Mill	Other
	Number examined							
Total	4, 474	1, 468	1, 818	1, 078	424	1, 404	898	923
Underground total	4, 168	1, 257	1, 486	876	89	284	77	198
Face	3, 883	326	456	335	42	145	43	100
Transportation	161	858	113	37	33	33	9	21
Maintenance and construction	52	52	890	47	11	96	5	18
Other	72	21	27	457	3	10	20	59
Surface total	41	54	120	59	282	977	706	631
Transportation	9	15	9	1	240	18	8	7
Maintenance and construction	9	14	68	14	19	863	38	49
Mill	15	16	12	10	10	39	628	47
Other	8	9	31	34	13	57	32	528
No principal	265	157	212	143	53	143	115	94

	Percent with silicosis							
Total	2.2	2.3	4.1	5.8	1.9	4.8	4.2	4.8
Underground total	2.3	2.5	4.8	6.8	4.5	13.0	14.3	16.2
Face	2.4	5.2	11.2	11.9	7.1	22.1	23.2	21.0
Transportation	.6	1.4	2.7	2.7	3.0	12.1		14.3
Maintenance and construction		1.9	2.0	6.4		1.0		16.7
Other	4.2	4.8		3.5			5.0	8.5
Surface total				1.7	1.1	2.6	3.8	1.0
Transportation					.8			
Maintenance and construction				7.1		2.7	7.9	2.0
Mill						5.1	3.8	2.1
Other					7.7			.8
No principal	.4	1.3	1.4	1.4	1.9	3.5		6.4

*Excludes workers in uranium mines.

surface operations. Workers whose present and principal occupation was at the face had a silicosis rate of only 2.4 percent. Most of these had worked only a short time. The highest silicosis rates for men with principal occupation of underground transportation, underground maintenance and construction, and other underground work were found among men now engaged at other surface work. There was very little silicosis among men with present and principal occupation in surface work and no long experience underground.

Geographical Location

As might be expected, the great majority of the 50 metal mines studied were located in the Western States. Mines in this region were placed in two groups, namely the Northwest, comprising the States of Idaho, Montana, Washington and Wyoming, and the Southwest comprising Arizona, California, Colorado, Nevada, New Mexico, and Utah. Crude silicosis prevalence rates were compared for these two regions with the following results for the Northwest and Southwest, respectively: total silicosis 4.4 and 4.4 percent, simple silicosis 2.9 and 2.8 percent, complicated silicosis 1.5 and 1.6 percent, and doubtful silicosis 0.9 and 0.8 percent. Considering the great difference in operating conditions for individual mines it was surprising that the combined data for the 17 Northwest mines and the 17 Southwest mines should yield such uniform silicosis prevalence rates.

The remainder of the country east of the Rocky Mountains was divided into three areas according to a rough estimate of the percent of free silica in the mine environment. Silicosis prevalence in areas of relatively high, moderate and low silica was as follows: total silicosis, 4.3 percent, 1.6 percent, and 0.7 percent, respectively; simple silicosis, 1.6, 1.2, and 0.6 percent; complicated silicosis, 2.7, 0.4, and 0.1 percent. Silicosis in the region with relatively high free silica was comparable to the prevalence in the Western States, but there was a sharply reduced rate in the other two geographical areas.

Silicosis According to Commodity Produced

Table V.20 and figure V.10 show the percent of workers with silicosis according to commodity produced. It appears that silica content of the dust was much more important than the type of commodity produced in affecting the crude silicosis rate. Excluding the iron and lead-zinc mines with low free silica exposures, the total crude rates for silicosis were much the same, namely: iron mines 4.2 percent, lead-zinc mines 4.8 percent, copper mines 3.6 percent, uranium mines 3.1 percent, and mines for all other commodities 3.7 percent. In the iron mines with low free silica exposures, silicosis

TABLE V.20.—*Silicosis among metal mine workers* according to commodity produced, by years at metal mines*

Mine commodity	Number of years at metal mines				
	Total	−10	10–19	20–29	30 and over
	Total examined				
Total	14, 076	6, 516	4, 324	2, 125	1, 111
Iron	1, 112	375	395	227	115
Lead-zinc	2, 622	1, 183	871	395	173
Copper	4, 010	1, 538	1, 381	748	343
Uranium	1, 589	1, 105	341	109	34
Other	2, 542	1, 674	541	220	107
Iron†	962	546	239	137	40
Lead-zinc†	1, 239	95	556	289	299
	Number with silicosis				
Total	476	7	93	193	183
Iron	47	1	10	12	24
Lead-zinc	127	2	27	50	48
Copper	146	1	21	58	66
Uranium	50	0	11	30	9
Other	95	3	22	41	29
Iron†	3	0	1	1	1
Lead-zinc†	8	0	1	1	6
	Percent with silicosis				
Total	3. 4	0. 1	2. 2	9. 1	16. 5
Iron	4. 2	. 3	2. 5	5. 3	20. 9
Lead-zinc	4. 8	. 2	3. 1	12. 7	27. 7
Copper	3. 6	. 1	1. 5	7. 8	19. 2
Uranium	3. 1	--------	3. 2	27. 5	26. 5
Other	3. 7	. 2	4. 1	18. 6	27. 1
Iron†	. 3	--------	. 4	. 7	2. 5
Lead-zinc†	. 6	--------	. 2	. 4	2. 0

*Includes uranium mine workers.
†Includes mines in low free silica limestone formations.

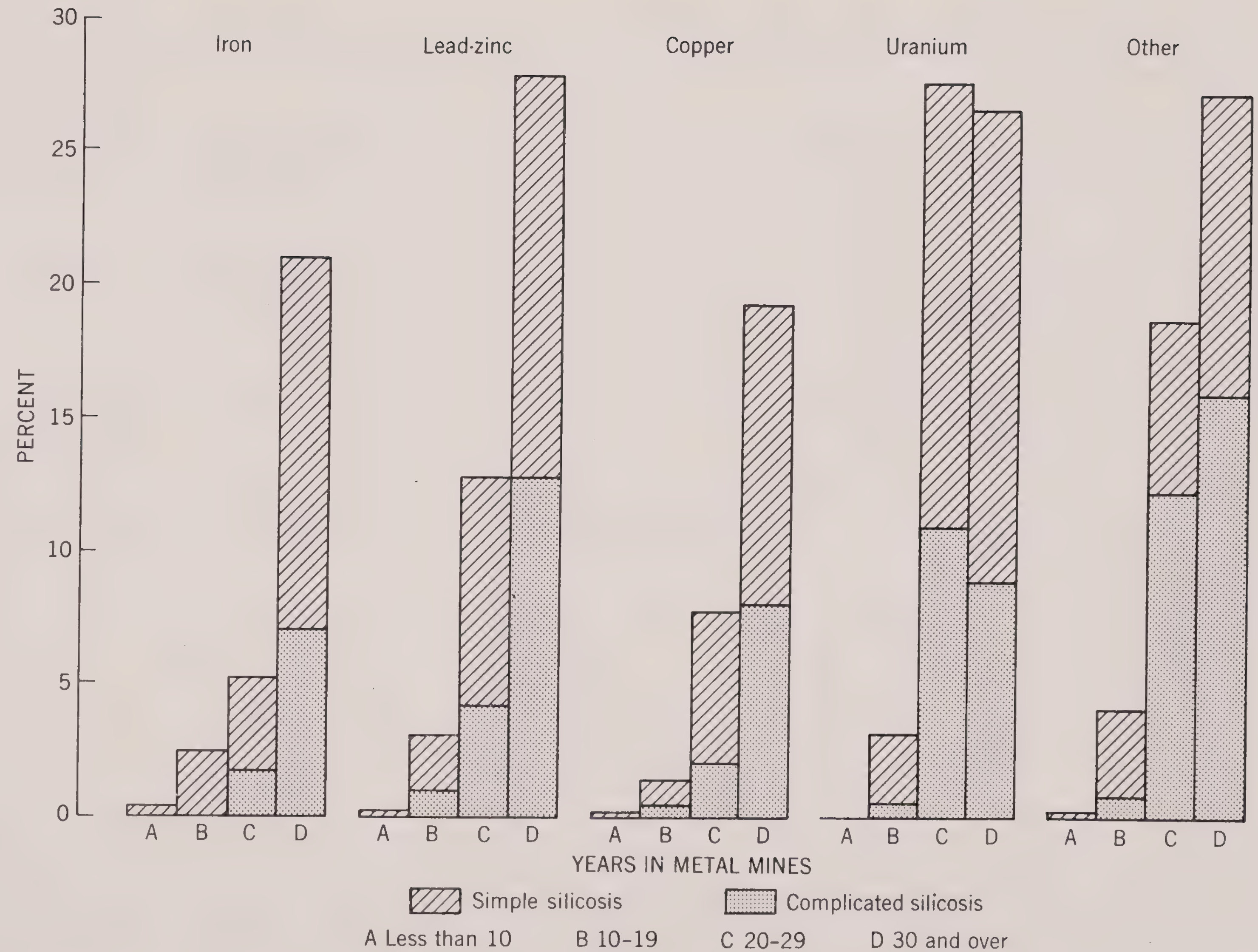

FIGURE V.10.—Percent of metal mine workers with silicosis according to commodity produced. (Excludes seven iron and lead-zinc mines in low free silica limestone formations.)

was found in 0.3 percent and in low free silica lead-zinc mines in 0.6 percent.

In no group of mines did persons with less than 10 years of experience show as much as 1 percent with silicosis. In the 10–19-year experience group (again excluding low free silica mines) the percent with silicosis was as follows: copper 1.5 percent, iron 2.5 percent, lead-zinc 3.1 percent, uranium 3.2 percent, and other commodities 4.1 percent. In the 20–29-year experience group, iron mines with 5.3 percent and copper with 7.8 percent were more favorable with respect to silicosis than were lead-zinc with 12.7 percent, other commodities with 18.6 percent, or uranium with 27.5 percent. The longest exposure groups, 30 years and over, showed iron and copper mines with about the same percent of silicosis. Lead-zinc, uranium, and other commodities had a higher silicosis rate. At mines with low free silica, silicosis was minimal even at the longest duration of exposure, with 2.5 percent for iron mines and 2.0 percent for lead-zinc mines.

Workers With Experience at One Mine Only and at Two or More Mines

Table V.21 and figure V.11 compare silicosis prevalence for persons with experience at one metal mine only and for persons who had worked at two or more mines. Men with employment at a single mine had the more favorable silicosis experience among almost all age groups of faceworkers, other underground workers, and surface workers, no matter what had been their length of service at metal mines. The one notable exception was the higher silicosis rate among faceworkers with 30 years or more of experience at one mine. Employment at several different mines apparently led to a more unfavorable dust exposure and consequently to a greater prevalence and earlier appearance of silicosis.

The rate of silicosis according to the number of years worked at metal mines for faceworkers who had worked at only one mine increased rapidly from 1.7 percent with 10–14 years of experience to 44.1 percent with 30 years and over. Faceworkers with experience at two or more mines showed a generally higher silicosis rate which rose with years of work from 2.6 percent to 27.0 percent. Other underground workers and surface workers did not show as rapid an increase in silicosis prevalence with increasing years at metal mines. Even after 30 or more years at metal mines, silicosis did not affect as much as 15 percent of these workers, whether they had experience at one or more than one mine.

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TABLE V.21.—*Silicosis among metal mine workers* with experience of 10 years or more at one mine only and at 2 or more mines by principal occupation and years at metal mines*

Years at metal mines	Number examined		Number with silicosis		Percent with silicosis	
	At 1 mine only	At 2 or more mines	At 1 mine only	At 2 or more mines	At 1 mine only	At 2 or more mines
	Total—all occupations†					
Total	3, 310	2, 199	201	207	6. 1	9. 4
10–14	1, 304	577	19	12	1. 5	2. 1
15–19	761	542	21	28	2. 8	5. 2
20–24	543	484	37	54	6. 8	11. 2
25–29	286	274	29	40	10. 1	14. 6
30 and over	416	322	95	73	22. 8	22. 7
	Face workers					
Total	1, 293	1, 304	113	145	8. 7	11. 1
10–14	586	345	10	9	1. 7	2. 6
15–19	261	317	6	21	2. 3	6. 6
20–24	199	293	21	39	10. 6	13. 3
25–29	104	149	13	22	12. 5	14. 8
30 and over	143	200	63	54	44. 1	27. 0
	Other underground workers					
Total	921	375	41	33	4. 5	8. 8
10–14	314	92	3	3	1. 0	3. 3
15–19	248	95	8	3	3. 2	3. 2
20–24	160	84	5	9	3. 1	10. 7
25–29	84	50	11	10	13. 1	20. 0
30 and over	115	54	14	8	12. 2	14. 8
	Surface workers					
Total	911	332	38	20	4. 2	6. 0
10–14	343	71	5	0	1. 5	--------
15–19	207	86	6	3	2. 9	3. 5
20–24	144	71	10	5	6. 9	7. 0
25–29	78	57	4	6	5. 1	10. 5
30 and over	139	47	13	6	9. 4	12. 8

*Excludes uranium mines and 7 iron and lead-zinc mines in low free silica limestone formations.
†Includes no principal occupation.

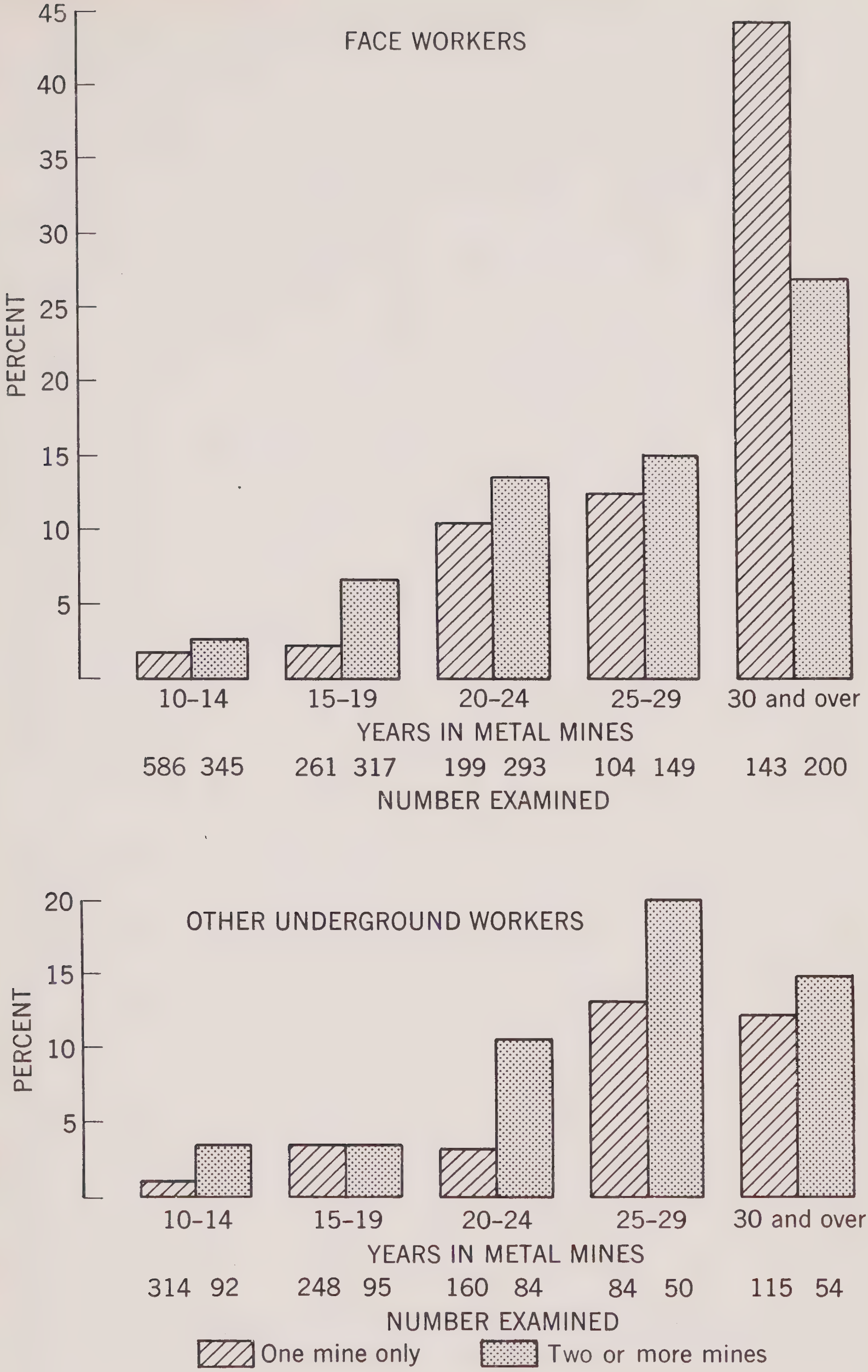

FIGURE V.11.—Silicosis among metal mine workers with exposure of 10 years or more in one mine only, and in two or more mines. (Excludes seven iron and lead-zinc mines in low free silica limestone formations.)

Silicosis Among Workers Excluded Because of Other Dusty Work

There were 671 metal mine employees excluded from the discussion because they had previously worked in other dusty employment which might be capable of producing silicosis. Table V.22 shows the experience of this group of workers compared with that of all metal mine workers in the study group. Workers with other dusty experience had about the same prevalence of silicosis as all metal mine workers when years in all kinds of dusty work were the same. For example, the former group with 30 or more years of dusty experience had 15.2 percent with silicosis compared with 16.5 percent for the latter group; for 10 to 19 years of experience the percentage with silicosis was 2.5 and 2.3 percent, respectively.

Types of dusty employment included coal mining, tunnel work, smelting, foundry work, quarrying, and the mining of various nonmetallic minerals. Approximately one-half of these men had spent from 5 to 10 years in other dusty work before entering metal mining employment. The remainder had spent 10 or more years in other dusty work.

Therefore, it appeared that the exclusion of 671 metal mine employees having had other dusty exposure from the mining population under study did not appreciably change the overall prevalence of silicosis in the study, when total years of exposure are taken into consideration.

TABLE V.22.—*Silicosis among metal mine workers with exposure in other dusty trades of 5 years or over according to total years in all dusty work*

Total years at* all dusty work	Total number examined	Number with silicosis			Percent with silicosis	
		Total	Simple	Complicated	Workers with other dusty experience	All metal mine workers†
Less than 10	68	0	0	0	--------	0. 2
10–14	130	1	1	0	0. 8	1. 5
15–19	146	6	5	1	4. 1	3. 0
20–24	121	12	10	2	9. 9	7. 6
25–29	101	10	6	4	10. 0	12. 1
30–34	61	9	6	3	14. 8	18. 2
35 and over	44	7	3	4	15. 9	14. 6

*Includes total years spent in metal mining and all other dusty work.

†Includes workers at 50 metal mines and uranium mines excluding those with work in other dusty trades of 5 years or over.

Silicosis by Periods of Work Experience Before and After 1935

Metal mine employees were divided into two groups according to the period of their work experience, namely, persons who had worked

at metal mines at some time before 1935 and had experience in some or all of the intervening years since then, and persons whose only work experience had been in 1935 or later. It is obvious that persons in the first group also must have worked in the second, since only employed miners were examined.

Table V.23 and figure V.12 show silicosis rates, specific for years at metal mines, for persons with experience beginning in each period. This permits some comparison of silicosis prevalence rates among workers in this study who had substantial exposure before dust control measures became widely used and those employed only during the subsequent 25 years or so. When the group of 43 mines, excluding those in low free silica limestone formations, was studied it was found that, among the relatively small group of workers with some mining experience before 1935 but who had worked at metal mines a total of only 10–14 years, the silicosis rate was 6.1 percent; a group of 1,818 persons who had worked the same number of years but only in 1935 or later had a rate of 1.5 percent. Corresponding figures for persons with 15–19 years at metal mines showed 8.3 and 3.3 percent with silicosis, respectively. After 20–24 years in metal mining, men with experience prior to 1935 had a silicosis prevalence of 12.7 percent compared with 7.2 percent for men with experience during or after 1935.

In mines which were located in low free silica limestone formations there was no silicosis among the 1,066 men who had worked 10–24 years, including some time before 1935. For the earlier period (before 1935), there was one case of silicosis after 25–29 years, four cases or 3.6 percent after 30–34 years, and three cases or 1.3 percent after 35 years or more. For the later period, those persons who had worked in 1935 or subsequently, there were only 3 cases of silicosis among 1,745 men. For any one duration the affected group did not reach 0.5 percent.

The trends shown in figure V.12 appear to indicate that although the prevalence of silicosis is substantially lower among men who began mining in 1935 or later than among those who worked before 1935, there continues to be a regular increase in prevalence with increasing years of experience in metal mining. In the more recent period the onset of silicosis was several years later than for persons with similar length of experience who had worked at some time before 1935. The curves for persons working in each period are of essentially the same shape suggesting that in recent years silicosis has been developing at a considerably slower pace than formerly, but that cases were still occurring.

TABLE V.23.—*Silicosis among workers at metal mines* by period of work experience and total years worked at metal mines*

Years at metal mines	Total number examined	Number with work experience: At some time before 1935 as well as later: Number examined	Number with work experience: At some time before 1935 as well as later: Number with silicosis	Number with work experience: Only since 1935 or later: Number examined	Number with work experience: Only since 1935 or later: Number with silicosis	Percent with silicosis: Worked at some time before 1935 as well as later	Percent with silicosis: Worked only since 1935 or later
	43 metal mines						
Total	10, 286	1, 765	290	8, 521	125	------	------
0–5	2, 423	2	0	2, 421	0	------	------
5–9	2, 347	24	0	2, 323	7	------	0. 3
10–14	1, 884	66	4	1, 818	27	6. 1	1. 5
15–19	1, 304	120	10	1, 184	39	8. 3	3. 3
20–24	1, 027	307	39	720	52	12. 7	7. 2
25–29	563	508	70	55	0	13. 8	------
30–34	444	444	95	0	0	21. 4	------
35 and over	294	294	72	0	0	24. 5	------
	7 iron and lead-zinc mines in low free silica limestone formations						
Total	2, 201	456	8	1, 745	3	------	------
0–5	415	0	0	415	0	------	------
5–9	226	0	0	226	0	------	------
10–14	285	2	0	283	1	------	0. 4
15–19	510	10	0	500	1	------	. 2
20–24	323	40	0	283	1	------	. 4
25–29	103	65	1	38	0	1. 5	------
30–34	111	111	4	0	0	3. 6	------
35 and over	228	228	3	0	0	1. 3	------

*Excludes uranium mine workers.

COMPARISON OF PRESENT WITH PAST STUDIES

In evaluating data from silicosis studies it must be kept in mind that, except in cases of massive exposure to high silica bearing dust, it requires a number of years, sometimes 20 years and over, of exposure to the dust before evidence of the disease exists on chest roentgenograms. The positive chest film is the evidence of excessive dust exposure over the past several years and not necessarily the concentration existing during the survey. Because of this long latent period, in cases where excessive atmospheric dust levels have been

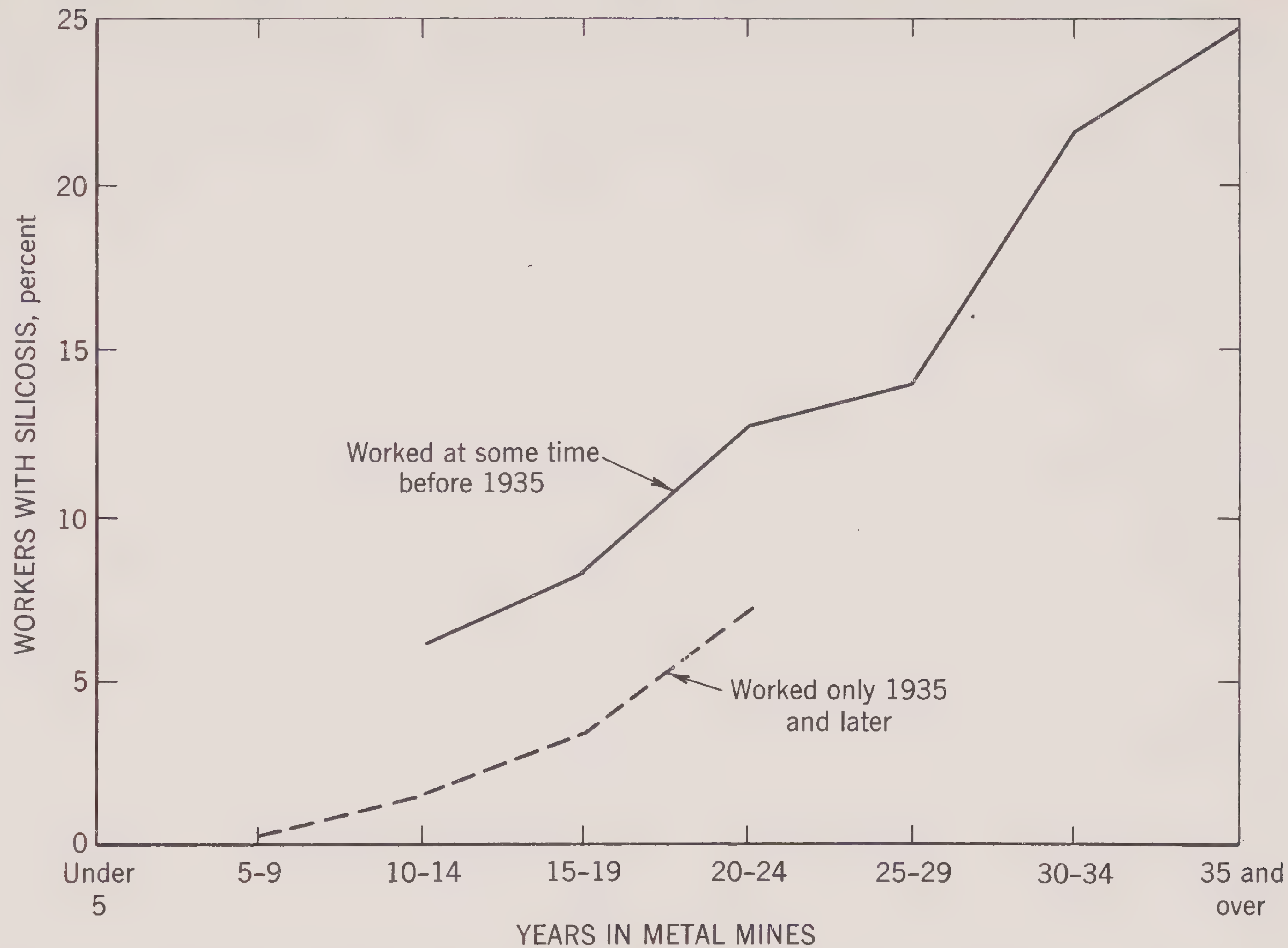

FIGURE V.12.—Percent of metal mine workers with silicosis according to period of experience and years worked in metal mines. (Excludes seven iron and lead-zinc mines in low free silica limestone formations and uranium mines.)

lowered, it may take a number of years before attending lower silicosis prevalence rates show up in subsequent chest roentgenographic surveys.

In reviewing the past studies of silicosis in the metal mines of this country, the above factor seems quite evident. In the very early studies before dust control measures were used appreciably, miners were exposed to massive dust concentrations. Within a relatively few years of exposure this resulted in a high prevalence of advanced silicosis accompanied also by a high prevalence of tuberculosis among the silicotics. In general, great advances have been made by the metal mining industry in controlling dust, especially since around 1935. This would not show up in an immediate lower prevalence of silicosis, however, because of the reservoir of miners exposed to dust prior to this period. It probably would not have its full impact until 20 to 30 years later. The only valid criterion of adequate dust control measures is the absence of new cases of silicosis developing in men whose only exposure is subsequent to the installation of dust control measures.

Fortunately the 1939 study of Non-Ferrous Metal Mine Workers in Utah presents considerable data which may be contrasted with data developed in 12 lead-zinc mines of the 1958–61 survey having similar characteristics. Approximately the same average percentage of free silica, 30 percent, was present in the settled dust samples of each group of mines. Table V.24 shows the prevalence of silicosis in the western lead-zinc mine workers examined in 1958–61 compared with Utah metal mine workers examined in 1939 according to years in metal mines. Table V.25 shows the weighted average dust levels at reasonably comparable selected operations during the same two surveys. The trend is favorable in that the prevalence of silicosis for lead-zinc mines in the 1958–61 survey was found to be approximately 40 percent lower than that found in the Utah 1939 survey. Even more striking is the 80 percent reduction in silicosis prevalence in the group employed in the mines less than 10 years and 72.8 percent reduction for the group employed 10–19 years. When consideration is limited to faceworkers only, there is an even greater decrease from the silicosis prevalence observed in the 1939 survey. The reduction amounts to 81.3 percent for the group employed in metal mines less than 10 years and 76.5 percent for the group with 10–19 years of employment. These groups are the best indicators of a reduction in exposure to dust during this interval of time. The environmental data of the 1958–61 survey shows a very favorable trend in reduction from the atmospheric dust levels found in the Utah 1939 survey. On the basis of median dust count values for lead-zinc mines in the 1958–61 survey, there was a 53 percent reduction in dust concentrations at dry crushing and 78 to 90 percent reduction in dust counts at other areas where comparisons could be made.

TABLE V.24.—*Silicosis in western lead-zinc mine workers examined in 1958–61 compared with Utah metal mine workers examined in 1939 according to years at metal mines*

Years at metal mines	Number examined	All silicosis		Simple silicosis		Complicated silicosis	
		Number	Percent	Number	Percent	Number	Percent
	1939 study						
Total	727	66	9.1	52	7.2	14	1.9
Less than 10 years	394	4	1.0	4	1.0	0	0
10–19 years	228	30	13.2	26	11.4	4	1.8
20 years and over	105	32	30.5	22	21.0	10	9.5
	1958–61 study						
Total	2,173	117	5.4	74	3.4	43	2.0
Less than 10 years	959	2	.2	2	.2	------	------
10–19 years	717	26	3.6	17	2.4	9	1.2
20 years and over	497	89	17.9	55	11.1	34	6.8

TABLE V.25.—*Weighted average dust concentrations (mppcf) at comparable occupations in 12 lead-zinc mines studied in 1958–61 compared with Utah metal mines studied in 1939*

Occupation	1939 study*—average	1958–61 study		
		Median	Range	
			Low	High
Underground				
Miner	23.1	3.1	1.3	17.6
Motorman	10.5	2.3	1.5	10.7
Hoistman	7.5	1.6	1.0	2.6
Timberman	18.9	1.9	.7	10.6
Surface				
Hoistman	3.8	.6	.5	2.3
Topman	9.4	1.1	.8	2.8
Crusher	14.3	6.8	2.1	17.3
Assayer	57.9	6.5	2.3	33.8

*1939 figures represent the average weighted average dust exposure for each occupation.

As pointed out earlier, due to the long periods of exposure necessary to produce silicosis, prevalence data at any one time represents the collective exposure of that group over the past several years. Thus the prevalence data on silicosis in the 1958–61 survey in most instances would represent exposures during the previous 20 years or more. Without carefully collected and recorded environmental data on a periodic basis over the period of exposure, it is not possible with validity to assign weighted levels of dust exposure to the workers. Such unfortunately is the case for the 1958–61 survey. Only in a very few cases do the environmental findings of the survey apply retrospectively more than a few years. It will be another 10–20 years before the full impact of the environmental levels of dust exposure found in the 1958–61 survey reveal themselves in correlative silicosis prevalence data. During this interval routine dust control monitoring and medical surveillance should be practiced to assure proper operation and maintenance of dust control procedures and the prevention of new cases of silicosis.

Case Histories

FIGURE V.13.—Simple silicosis.

Lead-zinc mine worker, white male, age 58, height 68 inches, weight 127 pounds.

Occupational history: Surface laborer 3 years and welder 8 years; flotation mill operator 21 years; also motor operator in lead smelter 9 years.

Medical history: Metal fume fever while welding in 1953—1-day duration. Moderate shortness of breath was only complaint.

X-ray chest film: Lung field markings classified in "suspect" category. Classical eggshell calcifications, some pleural abnormalities, and left apical bullae.

Diagnosis: Simple silicosis.

Comment: Classified as simple silicosis because of suspect lung field markings, definite eggshell calcifications, and occupational history. Case not included in metal mine study group, however, because of 9 years employment in a lead smelter.

FIGURE V.14.–Simple silicosis.

Copper miner, white male, age 50, height 66 inches, weight 198 pounds.

Occupational history: Repairman, operator, and supervisor of surface ore-crushing plant 27 years, all at one mine. Army, 3 years.

Medical history: Negative except for influenza 2 years previously. Off work 3 days.

Symptoms: Chest wheezing but only with colds. No shortness of breath.

X-ray chest film: I.L.O. Classification 3p.

Diagnosis: Simple silicosis, early.

Comment: Fine punctiform opacities scattered diffusely throughout lung fields with no other pathology noted. Considered good example of early silicosis. Only dust exposure had been 27 years in one copper ore-crushing surface plant.

FIGURE V.15.—Simple silicosis.

Copper miner, white male, age 63, height 67 inches, weight 140 pounds.

Occupational history: General miner in copper mines 21 years. Hand tramming in gold mine 2 years.

Medical history: Pneumonia in 1935, 9 days in hospital. No present symptoms.

X-ray chest film: Classified as category 2m, meaning a moderate degree of micronodular infiltration.

Diagnosis: Simple silicosis, early.

Comment: No symptoms were associated with these early silicotic changes.

FIGURE V.16.—Simple silicosis.

Mine crusher operator, white male, age 46, height 71″, weight 167 pounds

Occupational history: Various jobs up to shift foreman at mine crusher operation.

Medical history: All negative except "chest wheezes" with colds. No dyspnoea or other symptoms.

X-ray chest film: Classified as 2m–AX, indicating moderate micronodular infiltration of lung fields with a suspicion of beginning coalescence.

Diagnosis: Simple silicosis, early.

Comment: The ore-crushing mill operations were associated with a number of cases of simple silicosis.

FIGURE V.17.—Simple silicosis.

Miner, male, age 45, height 69″, weight 142 pounds

Occupational history: General metal miner 10 years (2 years in uranium mine). Miscellaneous underground jobs 5 years.

Medical history: Rheumatism.

Present symptoms: None.

X-ray chest film: Category 2n, meaning a moderate degree of nodular infiltration.

Diagnosis: Simple silicosis.

Comment: Original film was considered good example of I.L.O. Classification 2n. No symptoms of silicosis.

FIGURE V.18.—Complicated silicosis.

Lead-zinc miner, white male, age 45, height 72'', weight 155 pounds

Occupational history: Face miner 19 years; underground transportation 4 years.
Medical history: Off 28 days with pneumonia 3 years previously.
Symptoms: None.
X-ray chest film: Category A with 3n background. Small nodules diffusely scattered throughout chest. Small confluent areas both upper lobes.
Diagnosis: Complicated silicosis, early.
Comments: No symptoms were reported by this 45-year-old miner with early complicated silicosis.

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FIGURE V.19.—Complicated silicosis.

Miscellaneous metal miner, white male, age 42, height 73″, weight 165 pounds

Occupational history: Underground inspector 5 years; general miner 16 years; ore-crushing plant 1 year.

Medical history: None except he was told he had "dust on his lungs" in 1955.

Symptoms: None.

X-ray chest film: Category A with 3n background. Early confluence of opacities in both first interspaces. Hilar enlargement, emphysema, and slight distortion.

Diagnosis: Complicated silicosis, early, and emphysema.

Comments: This 42-year-old miner has diffuse nodular silicosis with small areas of coalescence. No symptoms were reported.

FIGURE V.20.—Complicated silicosis.

Copper miner, male, age 59, height 69'', weight 119 pounds

Occupational history: Driller and mucker 30 years; motorman 4 years; and laborer (nonmining) 5 years.

Medical history: Negative.

Symptoms: Wheezing in chest, constant productive cough, slight shortness of breath.

X-ray chest film: Category B with 3m background. Emphysematous areas and slight pleural thickening.

Diagnosis: Complicated silicosis, moderately advanced.

Comments: I.L.O. Classification B–3m. Moderately advanced complicated silicosis with moderate symptoms in a copper miner working 34 years underground.

FIGURE V.21.—Complicated silicosis.

Lead-zinc miner and supervisor, white male, age 55, height 71 inches, weight 180 pounds.

Occupational history: General miner 6 years; supervisory positions, part time underground, in several mines, 26 years.
Medical history: Recurrent fever and chest pain past 3 years. Has known he has silicosis for 20 years with progression of X-ray findings. Occasional attacks of "rheumatism." Several light attacks of "flu" during past 3 years.
Symptoms: Slight shortness of breath.
X-ray chest film: Category B with 3m background. Fine micronodulations diffusely scattered throughout lungs. Moderate coalescence both upper lobes.
Diagnosis: Complicated silicosis, moderately advanced.
Comments: Although in supervisory positions during most of his mining career, he has spent a considerable amount of time underground especially during the early years.

FIGURE V.22.—Complicated silicosis.

Copper miner, white male, age 66, height 69 inches, weight 138 pounds.

Occupational history: Underground pump operator and mucker 20 years; surface pump operator 6 years. Earlier jobs included truckdriving, ranching, and construction work.

Medical history: Denied any past illnesses or present symptoms.

X-ray chest film: Category C with 3n background. Eggshell calcifications, emphysema, both apices and bases, left hilum elevated, distortion in intrathoracic structures, and pleural changes. Confluent areas in both middle and upper zones.

Diagnosis: Advanced complicated silicosis.

Comments: Despite the X-ray evidence of advanced silicosis, this miner did not report any positive medical history or symptoms.

A health service data record was completed for each of the 50 mines where a medical survey was made. It contained information relating to the provision of hospital services, physicians, nurses, first-aid equipment, preplacement and periodic examinations, sickness absentee records, health and safety provisions, washing and toilet facilities, and change rooms.

Table V.26 shows that company hospitals were operated by one-fourth of the mines. Of the 12 company hospitals 9 were at mines with 300 or more employees. Neither company hospitals nor full-time physicians or nurses were found in mines with less than 100 employees. Among the 21 mines with 100–299 employees, 33.3 percent had full-time physicians and 38.1 percent had full-time nurses. Among the 11 mines with 300–699 employees, 63.6 percent had full-time physicians and a similar percentage had full-time nurses. The 7 largest mines, those with 700 or more employees, had slightly higher percentages. In addition, one mine specified a part-time physician and two mines a part-time nurse. There were 27 mines or 54.0 percent which did not have any full- or part-time service of a physician or a nurse.

TABLE V.26.—*Number of 50 metal mines* having specified health services according to size of mine*

Type of health services	Number of employees				
	Total	Less than 100	100–299	300–699	700 or more
Number of mines	50	11	21	11	7
Number of employees	19, 172	687	4, 237	7, 443	6, 805
Health services at mines:					
Company hospital	12	0	3	4	5
Full-time physician	19	0	7	7	5
Full-time nurse	21	0	8	7	6
Preemployment examination:					
Physical	44	7	19	11	7
Chest X-ray	43	8	18	10	7
Periodic examination:					
Physical	18	4	7	4	3
Chest X-ray	16	4	5	4	3

*Excludes uranium mines.

Except in the smallest mines, preemployment physical examinations and preemployment X-ray chest films were usually made. All mines with 300 or more employees had preemployment physical examinations and all but one of these included X-ray chest films. Regularly sched-

uled periodic examinations for all workers were much less common: 36.0 percent of the mines had such physical examinations and 32.0 percent included chest films. There was no definite trend according to size of mine for periodic examinations. In several additional mines there were regular chest film examinations, but only for certain classes of employees. It was reported that X-ray chest examinations were available upon request at several other mines but were not a routine procedure.

Based on average mine employment there were 7,025 metal mine workers at the 16 mines which required periodic X-ray chest films for all employees. This represents only 36.6 percent of the workers at all 50 mines studied who had the benefit of this important preventive measure in silicosis control.

The answers to questions pertaining to the provision of first-aid rooms, first-aid kits, and trained first-aid workers indicated that most of the mines had some type of these services with the exception that first-aid rooms were reported in less than one-half of the smallest mines.

Responsibility for the enforcement of health and safety provisions was commonly under the direction of the safety department. Thirty-nine mines had a full-time safety engineer and six mines had part-time safety engineers, leaving five mines without this service. Three-fourths of the mines had a safety committee.

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Smooth lining in airway to reduce fictional resistance and permit increased airflow.
(Courtesy of The Anaconda Co., 1963.)

CHAPTER VI

A Retrospective Study of a Silicosis Control Program

BACKGROUND

IT WAS RECOGNIZED that the metal mine study could be strengthened if detailed retrospective environmental and medical data were available for study. Information of this kind was necessary to demonstrate the effect of a long-term environmental and medical control program on the incidence and prevalence of silicosis. The opportunity to study one such program was presented in 1959, when the attention of the Public Health Service and the Bureau of Mines was directed to a report issued by the Saranac Laboratory dealing with environmental and medical studies in certain mines of the Lake Superior district. This program had been inaugurated in 1933 by the late Dr. L. U. Gardner, who had gained worldwide recognition for his silicosis studies while associated with the Saranac Laboratory. Originally, nine mining companies participated in the activity, but in 1946, three of the companies discontinued the contract with the Saranac Laboratory, and in 1946, 1954, and 1955, three other companies ceased operating.

An unpublished report, entitled "A Survey of the Progress of 25 Years in the Control of Dust and Silicosis" prepared by the field division of the Saranac Laboratory in March 1959, was reviewed by the Public Health Service and the Bureau of Mines. This report supplemented a 20-year progress report which had been made in 1953.

The report presented an X-ray classification of chest films taken on employees for the period 1934–58. This information is shown in table VI.1. It should be noted that the first four periods include five mining companies while the last period includes three companies. The striking fact shown by this table is the steady decrease over the entire period for all classifications of abnormal X-ray findings, including the most minor changes. Among the workers examined in 1934–38, the percent with silicosis was 19.8. In succeeding periods, it fell to 12.4, 9.3 and 5.9 percent until there were only 3.4 percent with silicosis in 1954–58. Workers examined who had marked peritruncal exaggeration amounted to 11.0 percent in the first period and 3.1 percent in the last period. As would be expected, with the decrease in abnormal

readings, the percent of workers with no peritruncal exaggeration rose from 44.2 to 83.8 percent.

TABLE VI.1.—*X-ray chest film classification (Saranac) of employees working in iron mines with contracts with the Saranac Laboratory by period examined*

X-ray chest film classification	Examination period				
	1934–38	1939–43	1944–48	1949–53	1954–58
Total number of employees examined	*5, 297	*7, 060	*7, 165	*7, 145	†5, 049
	Percent of employees examined				
No peritruncal exaggeration	44. 2	63. 4	70. 6	77. 6	83. 8
Peritruncal exaggeration (P_1)	25. 0	17. 1	14. 1	11. 7	9. 7
Marked peritruncal exaggeration (P_2)	11. 0	7. 1	6. 0	4. 8	3. 1
Silicosis (S_1, S_2, S_3)	19. 8	12. 4	9. 3	5. 9	3. 4

*Includes 5 mining companies.
†Includes 3 mining companies.

Another part of this Saranac Laboratory report deals with the records of 271 individuals who had X-ray changes since 1934 that warranted an increase in their classification and had remained on the payrolls as of 1952 and 1953. Among the 48 men whose dust exposure was entirely in the 15 years (1937–53), there was a change from normal to peritruncal exaggeration (P_1) involving 40 men and from (P_1) to marked peritruncal exaggeration (P_2) involving 8 men.* No man showed a progression which would be considered as silicotic. Men with exposure prior to 1937 did develop silicosis.

* The 1959 Saranac Laboratory Report defines P_1 and P_2 classification of peritruncal exaggeration as follows:

> "*PERITRUNCAL EXAGGERATION* (P_1).—The X-ray pattern is characterized by a slight accentuation of the shadows normally cast by the pulmonary blood vessels and is uniformly in evidence in both lung fields.
>
> "*MARKED PERITRUNCAL EXAGGERATION* (P_2).—May be defined as the general accentuation of the pulmonary linear markings, being quite pronounced and well defined, as described by Dr. Gardner, 'these changes, when associated with dust exposure, occur in the vascular sheathe making the vessels thicker than normal; consequently, heavier shadows are cast on the roentgenographic film.' Marked peritruncal exaggeration is rarely seen in the absence of dust exposure and can readily be accepted as evidence of pneumoconiosis, provided the exaggeration is uniform in the lung fields and there is a correlative industrial history."

In the period 1954–58, 41 employees of companies in continuous operation through 1958 showed progressive chest X-ray changes. There were 24 men whose only exposure was in the 21 years (1937–58). One of these men progressed to silicosis, 14 went from normal to P_1, and 9 went from P_1 to P_2. Seven of fifteen men with part of their exposure prior to 1937 progressed to silicosis.

The report concludes with the statements: "X-ray changes indicating the development of pneumoconiosis in this industry evolve very gradually. However, it seems reasonable to assume that sufficient time has not elapsed since the application of dust control to evaluate its effectiveness. With the exception of one case, no frank silicosis has developed from dust exposure subsequent to 1937, establishing the efficacy of control of free silica bearing dust. Pulmonary changes (P_1 and P_2), ascribed mainly to the inhalation of dust considered incapable of producing silicosis, have been indicated to a moderate degree by chest X-rays. Complete elimination of dust causing this type of benign reaction obviously is not obtainable in underground mines, but the reduction in the number of these cases over a 25-year period attests to the effectiveness of general dust control and further improvement can be expected through constant maintenance of present detection and preventive procedures."

Several meetings were held between representatives of the Bureau of Mines, the Public Health Service, the Saranac Laboratory, and the companies participating in the control program, at which time it was agreed that the information obtained by the Saranac Laboratory would be made available to the Public Health Service and the Bureau of Mines. Since it would have been a very time-consuming operation to review all of the available records, it was agreed that the following steps would be taken: (1) the Public Health Service would review a cross-section of X-ray chest films from the three mines included in the overall survey to determine if there was a close correlation between the readings of the Public Health Service and the Saranac Laboratory, and (2) the Bureau of Mines would review the environmental and historical records of these three mines. Insofar as possible, a history of the dust control activities, together with the dates of installation of the various control measures, would be documented and if possible, the dust concentrations would be reconstructed utilizing the companies' information. However, a dust survey would be conducted by the Bureau of Mines to determine the relationship between counts as reported by the companies and those obtained by the Bureau of Mines. These two steps were taken between 1959 and 1961.

It was determined that there was a close correlation between the X-ray readings of the Public Health Service and the Saranac Laboratory. The Bureau of Mines was able to document fairly closely the history of dust control procedures in the various mines and ascertain

that the dust counts, reported in the companies' records, correlated closely with the dust counts obtained by the Bureau of Mines.

Because this correlation of environmental and medical findings could be established, it was decided that it would be more expedient to make a detailed study of one participating mine rather than attempt to analyze a cross-section of all the data. After several conferences with the companies and representatives of the Saranac Laboratory, the Public Health Service and the Bureau of Mines suggested that the Montreal Mine, of the Oglebay Norton Co., be used for a thorough record study. The review of the historical data and information relating to dust concentrations was started by the Bureau of Mines on September 11, 1961, and completed October 25, 1961. The Public Health Service study of the medical records was begun in December 1961 and completed in November 1962. The following sections report the results of this retrospective study which has served to confirm essentially the conclusions of the Saranac Laboratory and to demonstrate the effectiveness of a medical-environmental control program in the prevention of silicosis.

THE STUDY OF MEDICAL RECORDS FROM ONE MINE

The plan adopted for the medical record study of the Montreal mine was to record the X-ray readings on each man beginning with the first film taken by the Saranac Laboratory and continuing from year to year as long as he remained with the company. A similar year-to-year job history was recorded including any dusty work he might have done before entering employment of the company. A continuous work history was obtained and the reason for any periods he did not work was entered under "comments."

The Public Health Service assumed responsibility for abstracting the data from the company and medical clinic records. A separate case history was prepared for each employee, consisting of two sheets, namely, the work history and the record of X-ray films taken. In order to be sure that no employee was omitted, a list was made containing each serial number issued under the Saranac Laboratory program. The first man whose X-ray was taken in 1933 was No. 1 and the series progressed without break until the last man, No. 2244, was reached in 1961. Once a man was assigned a Saranac Laboratory number, it was never changed so long as he remained with the same company, no matter how many X-ray films were subsequently taken.

The following classes of individuals were excluded from consideration: persons with work experience at the mine of less than 1 year, persons in nonmining occupations such as male or female officeworkers,

former employees who returned only for an X-ray chest film, and applicants who had X-ray examinations but were not hired.

A special effort was made, by searching insurance records and by consultation wih company officials, to learn the present status of the following classes of workers who were in the study group but had left mine employment: (1) all persons with silicosis or "infection" no matter how many years they had been employed; (2) all persons with 15 years or more of work experience in the mine. It was desired to ascertain if these former employees were now working elsewhere, were alive but not working, or if they had died and the cause. Copies of the official death certificates filed with insurance records, were found for most persons who had died, even those with short employment. The attempt was also made to find the reason for leaving employment, such as "quit," "fired," retired, or died for each person whose employment was terminated.

Preemployment work histories were secured from the clinical records made when a man was hired. After employment, it was possible to secure a month-by-month list of jobs held from official sources in the company employment office. Certain employees such as mechanics, pipemen, electricians, and other maintenance men are likely to spend part of their time on the surface and part underground. The actual years spent above and below ground were estimated after talks with officials who were familiar with working practices.

One of the decisions made early in the planning stages of this study was that X-ray chest film interpretations made over the years by radiologists at the Saranac Laboratory would be compared with interpretations of the same films by the panel of radiologists who served with the Public Health Service on the Metal Mine Study. Since dual readings of all of the tens of thousands of serial films available would be an unwieldy task, and spot sampling was considered insufficient, it was decided that the latest film on each man in the study would be read by the Public Health Service panel of radiologists. In addition, all men whose serial X-ray films showed any progression from normal to a silicotic category or to more advanced silicosis, according to the Saranac readers, were selected for special study. Each serial film from such men was read by the Public Health Service panel, as were a small group of films taken on other men which appeared to be of special interest.

In comparing the results of the Saranac Laboratory readings and the Public Health Service readings, it was found that there was a close correlation between films classified as positive for silicosis by each group, with the Saranac Laboratory readers tending to classify more films as positive for silicosis than the Public Health Service readers. Thus, out of 99 silicosis cases classified positive by the Saranac readers, 74 were considered positive by the Public Health Service readers:

On the other hand, only five cases (out of the total of 1,293 men included in the study) were classified as positive for silicosis by the Public Health Service radiologists and not so classified by the Saranac Laboratory radiologists; these five, however, were classified by the latter as presilicotic. In studying the selected cases with serial films showing progression from a normal appearance to that consistent with silicosis, the two groups of film readings were in close agreement as to when definite silicotic changes appeared. Therefore, in view of this close agreement, all subsequent analyses of X-ray films presented here will be on the basis of the readings from the Saranac Laboratory, which provided an interpretation for every serial film in all cases.

Description of the Members of the Study Group

During the period when the Saranac Laboratory was examining workers at the selected mine, there were 2,244 separate case numbers issued from 1933 through 1961. Each of these individuals had one or more X-ray chest films taken, as it was the practice to conduct annual chest examinations on all underground workers and biennial examinations on surface workers. There were as many as 28 serial chest films in the files of some men.

As explained previously, certain persons were eliminated from the study group. The following tabulation shows the number excluded according to a broad classification:

Reason for exclusion:	*Number of workers*
Worked less than 1 year	359
Nonmining occupations	222
Former employees	155
Applicants not hired	215
Total excluded	951

The group with nonmining occupations included 47 female workers, 27 male white collar workers, and 148 men who were hired as pinsetters in the company-owned bowling alleys. The 155 former employees represented men who had not worked for the company since 1933, but came back to have additional chest films taken.

The present study is limited to the remaining 1,293 men. Of this number 396 men had been hired and were already working when the Saranac Laboratory records began on January 1, 1933. The total number of years they had worked at metal mines both before and after 1933 was as follows: 1–5 years, 46 men; 6–10 years, 45 men; 11–15 years, 60 men; 16–20 years, 63 men; 21–25 years, 71 men; and 26 years and over, 111 men. Among these men there were 116 at

work prior to 1933 who remained with the company and were on the payroll at the time of the study in 1961–62.

Table VI.2 shows the employment history of the 897 men who were hired in 1933 and subsequently. The number of years on the payroll is shown for groups of men entering employment between certain specified dates. Since 446, or 49.7 percent, of these men were still employed at the time of the present study, their total years of employment were not completed. Also not taken into consideration is the fact that 201, or 22.4 percent, of the men had had other mining experience before being hired by this company. One-half of those with previous mining experience had worked less than four years, and 11.9 percent had worked 10 years or longer. None of the 897 men hired during 1933 or later had developed silicosis although 209 of these had worked 16 or more years in this mine. Included in the above group were 88 men who had already worked from 21 to 29 years without adverse effect at the time of the study.

TABLE VI.2.—*Distribution of workers hired in 1933 through 1960 according to year began working with the present company and number of years on the payroll*

Number of years on payroll of present company	Total number of men who began working 1933–60	Year began working with present company						
		1933–36	1937–40	1941–44	1945–48	1949–52	1953–56	1957–60
Total	897	113	121	217	151	201	88	6
1–5	299	18	36	91	55	53	40	6
6–10	216	26	22	28	9	83	48	------
11–15	173	11	8	12	77	65	------	------
16–20	121	6	20	85	10	------	------	------
21–25	63	27	35	1	------	------	------	------
26–29	25	25	------	------	------	------	------	------

It is interesting to note that 46.1 percent of the persons entering employment in 1933–36 continued to work for more than 20 years, 45.4 percent employed during 1937–40 worked more than 15 years, and 39.7 percent employed during 1941–44 worked more than 15 years. For each employment period, a large proportion were still working in 1962. Except during World War II, a relatively small percent worked for the shortest period, namely 1 through 5 years.

It is apparent that men listed toward the bottom of each column in table VI.2 include many who were still employed at the time of the study. Higher up the column all men, of necessity, would have completed company employment.

Among the 396 men working at the beginning of 1933, there were 83, or 21 percent, who showed evidence of silicosis. Sixteen additional

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men in this group developed silicosis after 1933 while they continued in employment. These silicotic workers will be described in more detail in a later section. Because of the curtailed demand for iron ore, the men working in 1933 were a reduced portion of the normal labor force. Evidently the older and more experienced men remained at work, hence the concentration of workers with long experience in metal mining.

The cause of death was known for 168 members of the study group, silicotic as well as nonsilicotic. Since it was not possible to trace the present status of all workers, other deaths have doubtless occurred which have not been recorded. Heart disease represented 42.8 percent of the known deaths, followed by 28.6 percent from violent causes such as industrial accidents, nonindustrial accidents, military action, and suicide. Cancer was the cause of 14.9 percent of the deaths and pneumonia of 5.4 percent. Only six deaths were attributed to pulmonary tuberculosis and there were two deaths attributed to cirrhosis of the liver. There was one death from each of the following causes: Brain abscess, enteritis, appendicitis, encephalitis, Addison's disease and peritonitis.

Workers With Silicosis

For the study group of 1,293 men, it was possible to estimate the prevalence of silicosis among those at work in 4 different years. This is shown in the following tabulation:

	1933	1940	1950	1960
Number at work during the year	*408	571	712	617
Number with silicosis during the year	83	79	51	9
Percent with silicosis	20. 3	13. 8	7. 2	1. 5

*Includes 396 men at work Jan. 1, plus 12 men employed during the year.

By definition, the study group included only men who worked longer than 1 year at the mine. As the older men with long experience before 1933 retired, few of the men remaining developed silicosis so that the prevalence fell rapidly. By 1960, there were only nine men with silicosis in the study group, a prevalence rate of 1.5 percent, which was the prevailing rate at the time of the Public Health Service study.

At the time of the first X-ray examinations in 1933, 83 cases of silicosis were found in the study group. Of these, 55 were classified as Stage I silicosis and 28 as Stage II silicosis. After 1933, there were

five of these men with Stage I whose X-ray reading changed to Stage II and one man with Stage II who changed to Stage III.

In the years subsequent to 1933, there developed 16 more cases of Stage I silicosis among men who at first were negative. Each of these men had worked before 1933 as well as later. Not a single one of the total of 99 cases of silicosis found in the study occurred among men who had worked only since 1933.

Table VI.3 shows for the 99 silicotic workers, their age and the years worked in metal mines at the time they terminated their employment with the iron mining company. It will be observed that three men were still at work at the close of 1961. More than two-thirds of these men were 60 years of age or older and 8.1 percent were 70 years or older at time of termination. A very small proportion, 6.1 percent, had worked less than 20 years in metal mines. Almost 40 percent had worked in this dusty trade for a total of 40 years or longer including some period of work after they had developed silicosis.

TABLE VI.3.—*Metal mine workers with silicosis according to age and years in mining when employment with the company was terminated*

Age of silicotic workers when employment terminated			Years in metal mining of silicotic workers when employment terminated		
Age in years	Workers		Years worked in metal mines	Workers	
	Number	Percent		Number	Percent
Total	99	100. 0	Total	99	100. 0
Under 50	12	12. 1	Under 20	6	6. 1
50–54	7	7. 1	20–24	6	6. 1
55–59	*12	12. 1	25–29	9	9. 0
60–64	22	22. 2	30–34	†18	18. 2
65–69	38	38. 4	35–39	†21	21. 2
70–74	5	5. 1	40–44	†21	21. 2
75 and over	3	3. 0	45 and over	18	18. 2

*Includes 3 men who were still working in 1961.
†Includes 1 man who was still working in 1961.

Among the 83 workers who were silicotic in 1933, approximately two-thirds had experience in two or more mines, while a third had worked in the study mine only. Table VI.4 shows the number of years in mining prior to 1933. Although it is not known how many years were required to produce the first evidence of silicosis, information is available on how many years these men had mined before 1933. Two-thirds had worked for 20 or more years. Men with mining experience less than 15 years represented one-third of the workers in one mine only and 10.5 percent of the workers in two or more mines.

TABLE VI.4.—*Mining experience previous to 1933 of workers who had silicosis in 1933 by years worked in 1 mine only and in 2 or more mines*

Total years in mining prior to 1933	Number of workers			Percent of workers		
	Total	In 1 mine only	In 2 or more mines	Total	In 1 mine only	In 2 or more mines
Total	83	27	56	100. 0	100. 0	100. 0
Less than 10 years	3	3	0	3. 6	11. 1	0
10–14	12	6	6	14. 5	22. 3	10. 5
15–19	13	1	12	15. 7	3. 7	22. 8
20–24	25	8	17	30. 1	29. 6	29. 8
25–29	23	8	15	27. 7	29. 6	26. 4
30 years and over	7	1	6	8. 4	3. 7	10. 5

Work History, Subsequent to 1933, of Employees With Silicosis

The work history of each man who had silicosis in 1933 or later can be traced in detail beginning with 1933 and continuing until he left employment with the mining company. These men fall into three groups: namely, 77 men with silicosis that did not progress, 6 men with silicosis that did progress, and 16 men working in 1933 who later developed silicosis.

The 77 men, who had silicosis in 1933 which did not progress continued working for varying periods thereafter. Five of these men left employment in less than 5 years, 15 stopped in 5–9 years, 15 in 10–14 years, 22 in 15–19 years, and 20 men continued working for 20 years or longer.

Table VI.5 shows the length of time worked for those who changed jobs within the one mine and those who continued in the same type of work until they left employment. As might be expected, the men who changed jobs stayed longer with the company than those who did not change. In the former group, 73.9 percent continued working for 15 years or more, while in the latter group, 25.8 percent worked that long. When the occupation of the 31 men who did not change jobs was examined, it was found that 19 were underground miners. Seven of these continued mining for 15 years or more. Six men were supervisors and remained in supervisory positions, all for less than 15 years. Four powdermen worked less than 10 years. A track cleaner worked 8 years and a surface laborer worked 11 years.

Among the 46 men, all underground, who changed jobs 1 or more times, 39 remained underground in various capacities and 7 moved

to work on the surface. The jobs held by these silicotic men when they were first examined in 1933 were as follows: 35 miners, 3 shift bosses, 2 track cleaners, and 1 each trackman, pumpman, drill repairman, slusherman, skip tender, and chuteman. Five of the seven men who moved to the surface were miners. Two-thirds of these 46 men spent 15 or more years in underground work after they had silicosis. All but one of the men who changed to the surface worked less than 10 years.

TABLE VI.5.—*Mining experience after 1933 of workers who had silicosis in 1933 which did not progress, according to job status and years worked*

Work history	Number of years worked after 1933					
	Total	0–5	5–9	10–14	15–19	20 and over
	Number of workers					
Total	77	5	15	15	22	20
Changed jobs 1 or more times	46	0	4	8	19	15
Remained in same job	31	5	11	7	3	5
	Percent of workers					
Total	100. 0	6. 5	19. 5	19. 5	28. 5	26. 0
Changed jobs 1 or more times	100. 0	0	8. 7	17. 4	41. 3	32. 6
Remained in same job	100. 0	16. 1	35. 5	22. 6	9. 7	16. 1

Nine of the sixteen men who developed silicosis after 1933 were underground miners when they were classed as silicotic and remained miners until they left employment. Four men changed from underground to surface work at some time after they became silicotic. Three men who were on the surface at the time of their silicotic diagnosis remained on the surface. Years of mining experience at the time of diagnosis as silicosis were as follows: less than 20 years, 6 men; 20–29 years, 5 men; and 30 years or over, 5 men.

The six men who changed from Stage I to Stage II silicosis or from Stage II to Stage III worked a relatively short time after the more severe stage was diagnosed. The number of years worked after the change in diagnosis were as follows: 1, 2, 6, 9, 11, and 12. Previously they had worked in the mining industry for 38, 36, 26, 22, 21, and 30 years, respectively.

The following tabulation shows the year in which each silicotic worker left employment in the mine:

Year:	*Number of men*	Year—Continued	*Number of men*
1935	2	1950	9
1936	2	1951	3
1937	1	1952	4
1939	5	1953	6
1940	4	1954	7
1941	3	1955	2
1942	2	1956	5
1943	3	1957	6
1944	9	1958	2
1945	6	1959	1
1946	1	1960	5
1947	4	Working	3
1949	4		

This indicates clearly that there was no wholesale dismissal of silicotic men, but there was a gradual departure as they reached retirement age or became unable to work any longer. Considering the fact that all of these men had worked before 1933 and that 83 men had silicosis in 1933, it is interesting that more than half remained in mine employment until 1950 or later.

The present status of most of the 99 silicotic workers was determined at the time of the survey in 1962. Thirty-two were known to be alive, 62 were known to be dead, and 5 were retired with status unknown. The cause of death was ascertained for 54 silicotic men. The largest group was 21 for heart disease, followed by 11 for cancer, 7 for accidents, 6 for tuberculosis, 3 for suicide, 3 for pneumonia, 2 for kidney disease, and 1 for Addison's disease. The proportion of deaths attributed to tuberculosis seems remarkably low among this small silicotic population although complete figures were not available.

Presilicotic Changes

Table VI.6 shows a classification of workers by lung field radiologic markings according to years in metal mines for persons with some experience before 1933 and experience only in 1933 and later. All workers with a total of 10 years or more in one or more mines are included. It is once again noticeable that no case of silicosis occurred in the group with experience only since 1933. In addition, there appears to be a notable decrease in presilicotic changes, especially marked peritruncal exaggeration (P_2), which drops from 15.6 percent in the group with earlier experience to 0.7 percent in the recent experience group. A comparison of men with 10–24 years in metal mining shows a decrease in the prevalence of P_2 markings from 5.4 for the pre-1933 group to 0.5 percent for the group with experience only since 1933.

TABLE VI.6.—*X-ray chest film readings by the Saranac Laboratory of workers with experience before and since 1933 by years in metal mines*

Lung field markings—Saranac reading	Years in metal mines					
	Total	10–14	15–19	20–24	25–29	30+
	Number					
	Some experience before 1933					
Total	444	27	39	45	53	280
Normal	105	14	14	11	14	52
P_1	172	11	19	25	25	92
P_2	69	1	2	3	5	58
Silicotic	*98	1	4	6	9	78
	Experience only 1933 and later					
Total	426	188	133	75	30	--------
Normal	405	185	127	67	26	--------
P_1	18	2	6	7	3	--------
P_2	3	1	--------	1	1	--------
Silicotic	--------	--------	--------	--------	--------	--------
	Percent					
	Some experience before 1933					
Total	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0
Normal	23. 6	51. 9	35. 9	24. 4	26. 4	18. 6
P_1	38. 7	40. 7	48. 7	55. 6	47. 2	32. 9
P_2	15. 6	3. 7	5. 1	6. 7	9. 4	20. 7
Silicotic	22. 1	3. 7	10. 3	13. 3	17. 0	27. 8
	Experience only 1933 and later					
Total	100. 0	100. 0	100. 0	100. 0	100. 0	--------
Normal	95. 1	98. 4	95. 5	89. 3	86. 7	--------
P_1	4. 2	1. 1	4. 5	9. 3	10. 0	--------
P_2	. 7	. 5	--------	1. 4	3. 3	--------
Silicotic	--------	--------	--------	--------	--------	--------

*1 case less than 10 years excluded.

A similar trend is observed in peritruncal exaggeration (P_1), which decreases from 38.7 to 4.2 percent. Again, for persons with experience of 10–24 years the prevalence of P_1 falls from 49.5 to 3.8 percent. Considering the normal films for persons with 10–24 years of experience, the early group shows 35.1 percent while 95.7 percent of men working only since 1933 had chest X-rays which showed no evidence of silicosis.

Another way of considering changes in X-ray markings is shown in table VI.7. Here, men with 10 years and more of work in the mine are placed in two groups: those who began working 1933–42, and those who began 1943–52. None developed silicosis, but 6.2 percent had some change in the first group and 1.3 percent in the second group. Except for one man who began in 1933–42 and worked 20 years, all changes were from normal to P_1, the smallest amount of peritruncal exaggeration in the Saranac Laboratory classification. This table does not include the changes which may have taken place among men with less than 10 years work. It is remarkable that there were so few evidences of progressive X-ray changes in lung field markings in those time periods where dust induced changes are most likely.

TABLE VI.7.—*Presilicotic changes in chest X-ray interpretation of men with 10 years or more of employment who began work in 1933–42 and 1943–52—Montreal mine*

X-ray chest film interpretation (Saranac Laboratory)	Total	Number of years worked in mine			
		10–14	15–19	20–24	25–29
	Men who began work 1933–42				
Total examined	161	21	52	58	30
No change:					
Number	151	20	52	52	27
Percent	93. 8	95. 2	100. 0	89. 7	90. 0
Change from normal to P_1	9	1	0	5	3
Change from P_1 to P_2	1	0	0	1	0
Percent with change	6. 2	4. 8	0	10. 3	10. 0
	Men who began work 1943–52				
Total	225	158	67	------	------
No change:					
Number	222	157	65	------	------
Percent	98. 7	99. 4	97. 0	------	------
Change from normal to P_1	3	1	2	------	------
Percent with change	1. 3	0. 6	3. 0	------	------

THE REVIEW OF ENVIRONMENTAL AND HISTORICAL RECORDS

A study to obtain historical information on dust and related environmental conditions was conducted in the period from September 11 to October 25, 1961, at the Montreal mine, Oglebay Norton Co., Montreal, Wis. Information was obtained from company files, by conferences with company personnel, and from Bureau of Mines files. All available and pertinent information on the history of the mine from the discovery of iron ore in 1885 through 1960 was reviewed. The wealth of data made available has been condensed considerably because of space limitations of this report.

History of Operations and General Information

Iron ore was first discovered within the present property limits of the Montreal mine in 1885. The first efforts to produce ore from the new discovery were by small open pit operations. At the time of the study, the Montreal mine property embraced the former Montreal, Trimble, Ottawa, and Section 33 mines. The first three of these mines recorded iron ore shipments in 1886 and shipments from the Section 33 mine were made in 1889.

No record was found of the date when the first shaft was sunk on the property, but early underground production was obtained through numerous shallow shafts sunk at isolated spots along the strike of the iron formation. As the workings became more extensive and it became known that ore existed at greater depths, inclined shafts were sunk in the quartzite footwall. By 1912, iron ore was being mined through four shafts from the property now embraced by the Montreal mine. Two shafts on the west side were called the Montreal mine, and two shafts on the east side were called the Ottawa mine. Sometime prior to 1921, two five-compartment inclined shafts were sunk in the quartz slates 300 feet south of the footwall. These shafts replaced the four old shafts and were operated independently as the Ottawa and Montreal mines. These two shafts, designated as Montreal No. 4 and Montreal No. 6, were still in service at the time of the study.

A comprehensive geological study in 1920 revealed possibilities of orebodies at greater depth. An exploration program confirmed the geological deductions and determined the lateral limits of the ore to a considerable depth. A study of deep mining followed, and the primary question was whether or not shafts at each end of the property should be continued or whether a new shaft should be sunk to handle total production. Furthermore, there was a block of unexplored

ground in the center of the property into which the orebodies were pitching.

Sinking of a centrally located vertical shaft (No. 5) was begun on August 16, 1921. The shaft was 3,036 feet deep when completed in June 1928, and records revealed that it was sunk in at least three "lifts." The first 600 feet of the shaft passed through quartz slates and the remainder of the shaft was in greenstone. Connections to underground workings were made as each "lift" was completed.

At the time of the study, No. 4 shaft was a ventilation and escape shaft. No. 5 shaft was the main hoisting and pumping shaft from the 35th level to surface. No. 6 shaft was used for hoisting men and supplies. Inside the mine an auxiliary shaft, sunk during the years 1951 to 1956 and located 1,100 feet north of No. 5 shaft, extended a vertical distance of 1,894 feet below the 31st level. This shaft was connected at several levels with the No. 4 and No. 6 shafts.

Over the past 40 years, mine employment had varied between approximately 300 and 900 men (see table VI.8). During this period 25 to 30 percent of mine employees worked on surface.

During the study, the mine was worked two shifts a day, 5 days a week. Hoisting was conducted on three shifts. The mining places extended for about 6,000 feet in an east-west direction and from 3,000 to 4,000 feet below the surface. Average annual production for the past 20 years had been approximately 1 million tons of iron ore.

Geology

The Gogebic Range iron formation consists of a series of sedimentary rocks, with numerous intrusive diabase dikes. The members of the iron formation were easily identified and regular in both strike and dip, except where displaced by faulting. The footwall of the formation was a quartzite, grading downward into a slate and resting on a greenstone basement rock. The members of the iron formation in ascending order from the quartzite were the Plymouth, Yale slate, Norrie, Pence slate, Anvil, and other upper slates. The hard quartzite footwall and the middle band of Yale slates were in general, the impervious members of the formation. Productive horizons were the lower Plymouth, upper Yale, Norrie, and lower Pence. The bulk of the ore occurred in the Plymouth and Norrie members of the formation. The Plymouth and Norrie members which overlay the ore bodies were composed of bands of very hard unaltered chert interspersed with bands of softer leached material.

The ore was hematite and classified as soft. Most of it had a claylike consistency with hard ribs throughout. Relatively large open-

TABLE VI.8.—*Statistical data on company operations in Montreal mine*

Year	Tons of ore produced	Tons of rock hoisted	Feet of entry work	Average total employment
1921	151, 138	35, 813	11, 130	311
1922	395, 527	65, 686	31, 195	478
1923	792, 942	55, 051	40, 503	757
1924	798, 006	77, 411	65, 593	736
1925	912, 056	123, 649	64, 825	798
1926	1, 105, 899	158, 563	86, 013	917
1927	1, 162, 116	103, 053	57, 500	802
1928	1, 084, 873	114, 176	40, 066	789
1929	1, 270, 370	97, 761	43, 973	896
1930	1, 043, 097	152, 108	38, 967	653
1931	753, 992	90, 580	20, 010	448
1932	402, 732	25, 119	12, 917	343
1933	210, 289	21, 995	6, 133	360
1934	579, 965	29, 003	11, 674	375
1935	678, 127	69, 187	9, 933	430
1936	802, 536	35, 651	16, 021	455
1937	953, 810	68, 759	24, 971	508
1938	796, 730	94, 025	20, 968	464
1939	808, 973	109, 741	17, 802	559
1940	1, 015, 463	98, 689	23, 958	558
1941	1, 080, 136	96, 798	26, 758	609
1942	1, 118, 294	69, 260	26, 196	617
1943	1, 120, 793	84, 494	14, 227	641
1944	1, 081, 503	69, 320	6, 953	635
1945	1, 113, 929	50, 296	6, 467	585
1946	857, 227	42, 320	5, 767	610
1947	1, 153, 196	57, 765	7, 855	638
1948	1, 088, 034	59, 479	8, 104	641
1949	962, 119	58, 943	8, 184	658
1950	1, 094, 793	110, 901	13, 195	697
1951	1, 119, 703	127, 166	15, 507	715
1952	977, 191	122, 893	16, 179	710
1953	1, 126, 144	155, 380	19, 522	729
1954	1, 014, 683	154, 504	21, 270	724
1955	981, 633	150, 933	22, 625	727
1956	883, 073	137, 157	20, 243	730
1957	966, 049	190, 597	25, 552	733
1958	693, 723	151, 372	20, 695	693
1959	490, 490	68, 564	10, 184	639
1960	955, 394	103, 701	13, 530	617

ings, especially under new capping, could be made in ore without immediate caving. Three grades of ore, Bessemer, non-Bessemer, and manganiferous, were produced. Through the years the ores have analyzed from approximately 57.5 to 60 percent iron, dry, and from 7.0 to nearly 9 percent silica.

Total and Free Silica Determinations

Free silica determinations for the various members of the iron formation were not available. An analysis of greenstone samples made in 1936 revealed the following: free silica 0–12 percent, magnetite 2–7 percent, sericite 1–2 percent. The remainder was plagioclase, hornblende, epidote, etc. Another file notation stated that greenstone averaged about 10 percent free silica.

A free silica determination made by the Bureau of Mines revealed that a composite sample of the ore hoisted in one day contained 4 percent free silica. Settled dust samples collected at various underground and headframe locations contained from 5 to 23 percent free silica.

Numerous samples of the various members of the iron formation were analyzed for total silica. Averages of these analyses are tabulated below:

Number of samples	Material analyzed	Average total silica, percent
13	Greenstone	58. 60
129	Quartzite and quartz slates	65. 70
11	Dike	36. 00
27	Cherty iron formation	36. 23
10	Yale and Pence slates	43. 88

Quartzite varied from a low of about 40 to a high of nearly 90 percent total silica, dike 18 to 45 percent, cherty iron formation 16 to 85 percent, and slates 27 to 63 percent.

Mining Methods

Various methods of mining have been employed throughout the Montreal group of mines. In the early days of mining in the area an overhand, open-stoping method of mining was utilized. Entry into the mines was made through numerous shallow shafts sunk in the iron formation. Ore was hand mucked into end-dump tram cars and hand trammed to raises or the skip pocket.

Wherever the hard strong ore persisted, the mining method was gradually changed to a sublevel open-stoping method with a 33-foot sublevel interval. The first sublevel above the haulage level was a mill raise and blasting sublevel. The block of ore to be stoped varied from 100 to 200 feet in height and was about 200 feet in length. Width of an orebody varied from 15 to 100 feet. Manway raises were

driven through the orebody parallel to the quartzite footwall at intervals of 200 feet. These raises were connected by sublevel drifts at 33-foot inclined intervals. Midway between manway raises a mill raise was driven up through the orebody along the footwall and a slot was formed from footwall to hanging wall through the orebody. The ore was mined by widening the slot and then benching around the mill raise. Mining was accomplished by retreating to the manway raises. As the stope was enlarged additional mill raises on 25-foot centers were driven to intersect the stope. The sublevel open-stoping method of mining was terminated in 1940.

In the western portion of the property, the soft, granular ore was developed by driving three or four parallel haulage drifts on 50-foot centers. Inclined raises were driven on alternate sides of the drift at intervals of 25 feet and extended to the top sublevel. Sublevel intervals were 25 feet and branch raises were driven to form a grid or checkerboard pattern of raises on 25-foot centers on each sublevel. With the introduction of double-drum electric slusher hoists in 1925, it was no longer necessary to drive so many raises. At that time, a series of raises was driven from main level crosscuts at about 33-foot intervals, and connections were made between raises on each sublevel. The ore then was slushed through these connecting drifts and crosscuts to the raise on each sublevel. Cars of ore were loaded through chutes on the haulage level. Following the introduction of slushers on the mining sublevels, slushers were utilized for loading ore into cars on the haulage levels. However, due to the inability of the slusher operators to handle the ore from the innermost raises, a method of mining evolved whereby only one raise, a short distance from the crosscut, was driven up parallel to the footwall. Cross mucking then was begun on each sublevel and all ore from each block was transferred to the loading drift through a single ore pass raise.

At the time of the present study, ore was being mined by a sublevel caving method. Main level interval was 150 to 200 feet and the sublevel interval was 50 feet. Ore bodies were approached by main level drifts in the quartz slates south of the footwall. Main-level crosscuts were driven north from the slate-rock haulage drifts at intervals of 300 to 400 feet. Loading drifts, from which trains were loaded, were driven from main-level crosscuts into the ore bodies for about 60 feet. A single loading drift serviced a block of ore which measured from 20 to 150 feet from foot to hanging wall. A double-compartment mining raise, without chutes, was driven up from each loading drift parallel to the quartzite and about 35 feet from the mouth of crosscuts. This raise was driven to the top sub, and subs were cut out at 50-foot intervals. On the top sub a crosscut was driven south into the footwall rock and a ventilation, supply, and manway raise was driven to the level above, holing through in rock. From the raise on

the top sub, a transfer drift was driven east and west approximately 150 to 200 feet in each direction or to the limits of the block. This completed the development of a 300- or 400-foot block of ground.

Breaking ore by the sublevel caving method consisted of crosscutting to the limits of the ore and breaking and caving the side and back pillars in retreat. The ore was blocked out in 50-foot pillars along the strike of the formation starting from a point 150 or 200 feet east or west of the mining raise and retreating to the raise.

In attacking a 50-foot pillar, two crosscuts were driven on 25-foot centers from the main transfer drift. A manway was made by raising midway between these crosscuts and driving an untimbered subcrosscut 25 feet above the mining sublevel. Openings from the inside of each crosscut were carried upward and enlarged until they broke through to each other and the manway subcrosscut 25 feet above. From the manway subcrosscut the stope was enlarged from narrow benches. As slice holes were blasted in the walls, the back caved until it arched over the width of the opening created. Slicing was carried on until the protecting shell of ore around the stope was remarkably thin. Supporting ribs were then cut and the stope entered the dropping stage which continued for several shifts. The opening made was confined within the limits of the 50-foot-wide pillar. After the pillar was mined back to the transfer drift, during which time the legs were also removed between stope holes, a stope was opened on the footwall side of the slushing drift or over the drift in the same manner.

History of Organized Safety Activity

A safety department was first organized during 1923. Records revealed that the department was headed by a safety engineer, but information on the size and specific duties or objectives of the department could not be found.

Sometime during the late 1920's the safety department was reorganized and a safety director was appointed. Under the director there were two safety engineers and three underground inspectors. Each inspector was assigned to one of the three shaft areas.

The first ventilation engineer was hired in 1933, and through 1935 he devoted full time to ventilation, dust counting, dust control measures, and recordkeeping. In 1936 the ventilation engineer was appointed safety and ventilation engineer and was made the head of the safety department. About the same time, an assistant safety and ventilation engineer was added to the department, which, during the late 1930's was composed of four men.

The safety department continued to perform safety and ventilation duties until 1954, at which time ventilation duties were trans-

ferred to a separate supervisory department. At the time of the study, the safety department consisted of a safety director, an underground inspector, and a clerk who also did dust counting and certain surface inspections.

First mention of the use of safety equipment was made during the sinking of the third "lift" of No. 5 shaft in 1928. Eye protection at that time was provided by wire-mesh goggles.

At the time of the study, the use of hard hats, safety glasses, and safety footwear was mandatory. Other personal protective equipment or devices were provided where necessary and recommended. Respirators were required to be worn by miners during drilling and scraping operations.

First-aid boxes and equipment were provided at key points on surface and underground. A well-equipped first-aid room was provided in the central change house.

Meetings constituted an important part of the safety program. Information vital to the advancement of safety was discussed at weekly underground foremen's safety meetings and monthly Central Safety Committee meetings, which were attended by all foremen and top management. At these meetings, past accidents were reviewed, findings during safety inspections, and other pertinent safety information and fire prevention measures were discussed.

The company had subscribed since 1940 to a service which provided safety posters for bulletin board use on surface and underground, supervisory educational and training pamphlets, management information bulletins, and services in connection with mine suggestion system. Personnel from the mine had regularly participated in safety programs and meetings sponsored or conducted by mining companies and other agencies. The company had maintained membership and had actively participated in the Lake Superior Mines Safety Council since the early 1920's and the mining section of the National Safety Council since the early 1930's. Numerous employees had received Bureau of Mines first-aid, mine rescue, and accident prevention training. Mine rescue crews were trained twice a month by company personnel. Mine air collected at several points throughout the mine was analyzed semiannually by the Bureau of Mines.

The company had for many years maintained a doctor's office and provided medical care for employees. The date of constructing and equipping the first office could not be ascertained, but records were found which revealed that the company had purchased an X-ray machine in 1914 and replaced it in 1928. New X-ray equipment was purchased in 1950.

From May 25 to November 1, 1933, the mine was temporarily closed for economic reasons. Prior to the closing about 470 employees were given physical examinations including chest X-rays. When the mine

reopened in November 1933, all employees were reexamined. This was the start of preemployment physical examinations. Late in 1933 the company began annual physical examinations for all underground employees. Surface employees received a physical examination every other year. Examinations were given as often as quarterly in occasional questionable cases. Hoistmen were given a complete physical examination every 6 months.

Since 1941, the mining company had rented doctor's office space in a city-owned building and furnished the necessary equipment. An X-ray technician was employed full-time by Saranac Laboratories for duty at this office and one other on the Gogebic Range. A full-time qualified laboratory technician was provided by the company. Annual physical examinations were scheduled and arranged for by the safety department.

Ventilation

In the early days of mining in this area, the shallow mines were sufficiently ventilated by natural means. The open-stoping method of mining created underground openings and eventual surface subsidence openings through which air could easily circulate. Natural ventilation, therefore, continued to provide circulation throughout the Ottawa and Montreal mines as long as the open-stope method of mining continued. This method of mining was practiced to a depth of nearly 3,000 feet on the east side of the property and to about 1,200 feet on the west side of the property. No records of fan installations, air quantities, or other ventilation data were found for the years prior to 1920.

After sinking the central shaft (No. 5), which was completed in June 1928, company records and reports revealed that "a plentiful amount of air tended to flow through the mine during the winter months, but during the hot summer months a shortage of air was noted in the workings on the western end of the property." Records revealed that at least 11 auxiliary fans ranging from 5 to 15 horsepower were in use throughout the property by June 1930.

To relieve the lack of ventilation during summer months, a 60,000-c.f.m. Jeffrey Aerobladed rotary blower powered by a 25-hp. motor was installed on the 27th level, No. 5 shaft, in August 1930. This is the first primary fan installation on record for this mine. In December of 1931 a second primary fan, a 60-inch Jeffrey Aerovane fan powered by a 20-hp. motor, was installed on the 29th level of No. 5 shaft. It may be assumed that either or both fans were pulling air down No. 5 shaft, or from open stopes in No. 5 shaft territory, and forcing air toward No. 4 shaft workings as the records showed that No.

5 shaft was maintained downcast in the early days and No. 4 shaft was upcast due to natural atmospheric pressures.

In 1932 four No. 2½ Anaconda-type Troy Sorocco blower fans were put into service in various working places. This raised to 15 the total number of auxiliary fans on record at this time. No records were found to indicate where these fans were located or how much air was being coursed through underground workings.

Reports revealed that after a ventilation engineer was hired, an intensive study of existing and proposed ventilation measures was undertaken. One of these reports, dated May 1933, was prepared jointly by a representative of Saranac Laboratories and the company ventilation engineer. This report disclosed that the Montreal mine was divided into three main areas for ventilation purposes: The Nos. 4, 5, and 6 shaft territories. Air for No. 6 shaft territory entered the downcast No. 6 shaft to the 33d and 34th levels from where it was coursed westward and/or upward through workings and eventually vented into the open stopes in No. 5 shaft territory. Air for No. 5 shaft territory was drawn down No. 5 shaft to the 27th and 29th levels by the fans on each of these levels. The fan on the 27th level forced the air into the workings in the hanging wall formation. From the 27th level the air was coursed upward with the aid of auxiliary fans and ventilation doors. This air was exhausted into the open stopes west of No. 5 shaft above the 25th level. Air for the No. 4 territory entered the mine on the 29th level at No. 5 shaft. This air was forced westward through the haulage drift and haulage crosscuts to both the footwall and hangingwall workings in the No. 4 territory. The air was then coursed upward through raises and exhausted into No. 4 shaft on the 27th level. No record was made of the quantities of air available or the length of time the mine had been ventilated in this manner. This system of ventilating the mine had several disadvantages: Cold winter air was encountered on the levels and at the shaft by men coming from warm working places, ice formed in the shafts maintained downcast during the winter months, dust from activities in the shaft was carried into the mine with the downcast air, and dust was introduced to working places by moving air through raises countercurrent to the movement of ore. Several proposals for correcting these conditions were advanced. It was finally decided that No. 4 shaft should be maintained upcast, but experimentation was necessary to determine the best possible source of fresh air from the No. 5 and No. 6 territories. It was proposed that various sources of air and methods of circulation be tested experimentally. Dust, humidity, and temperature determinations were made and air velocities were measured at principal points throughout the entire mine during these ventilation experiments. Some of this experimentation was made

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in the late spring of 1933, but was halted when the mine was closed for economic reasons on May 25.

In the fall of 1933 work was begun on the construction of an air heating unit and fan installation at the collar of No. 4 shaft. It was decided to maintain No. 4 shaft upcast, but it was anticipated that air would have to be heated if it was ever decided to make No. 4 shaft downcast. About this time a decision also was made to obtain fresh air for No. 6 shaft territory from the open stopes in that area. Accordingly, in November of 1933 a 40,000 c.f.m. fan was installed at the collar of No. 6 shaft and operated exhausting. The fan and heating unit installation begun in the fall of 1933 was completed at the collar of No. 4 shaft in September of 1934. The fan was operated exhausting and drew approximately 65,000 c.f.m. through No. 4 territory and up No. 4 shaft. For most of the period from late 1933 through 1934, No. 5 shaft was maintained downcast. All primary fan installations were made to provide flexibility so that different schemes of ventilation could be tried experimentally.

The foregoing discussion is presented to illustrate the degree of detail with which records of ventilation practices had been kept. As space limitation does not permit similar detailed account of ventilation procedures and improvements throughout the life of the mine, the following salient data relating to ventilation are presented in summarized form:

Before 1933

At least 11 auxiliary fans were in use by June 1930.

First primary fan was installed in August 1930.

Second primary fan was installed in December 1931.

Four additional auxiliary fans were put into service in 1932.

1933–36

Full time of first ventilation engineer was devoted to ventilation, dust counting, and dust control measures.

Mine air analysis started.

A primary fan was installed at the collar of No. 4 shaft.

A primary fan was installed at the collar of No. 6 shaft.

Primary and auxiliary fans were continually being relocated to provide ample circulation of air. Approximately 150,000 c.f.m. of air was being circulated through the mine at the close of this 4-year period.

First installation of automatic ventilation doors which permitted the passage of ore trains without interrupting the main air current.

1937–40

A primary fan was installed on the 29th level of No. 5 shaft. Other primary fans were now located on the 33d level of No. 6 shaft, the

27th level of No. 5 shaft, and at the collar of No. 4 shaft. These four fans provided a total of 180,000 c.f.m. of air.

The number of auxiliary fans was increased from 15 to about 30.

Began driving special ventilation raises in rock to avoid contamination of air being coursed to working places.

1941–44

A fifth primary fan was installed on the 31st level of No. 6 shaft. Forced ventilation was increased from 180,000 to 200,000 c.f.m.

The number of auxiliary fans at the close of this period was 35.

By the end of this period fresh air for the mine was being drawn through open stopes in No. 5 and No. 6 shaft territories.

1945–48

Fresh air was supplied to lower levels in No. 6 shaft territory through a special rock ventilation raise driven from the 38th to the 35th level.

Underground primary fans were relocated during this period, but forced ventilation was not increased.

The number of auxiliary fans in use was increased from 35 to 53.

1949–52

A sixth primary fan was installed in the rock ventilation raise on the 38th level of No. 6 shaft. Forced ventilation was not increased.

Special rock ventilation raise in the No. 6 shaft territory was driven from the 35th to the 33d level to provide a more positive access for fresh air.

A total of 67 auxiliary ventilation units was now in service.

1953–56

One new primary fan was installed on the 37th level of No. 6 shaft to replace two of the three fans in service in that area. Forced ventilation virtually unchanged.

The number of auxiliary fans was increased from 67 to 84.

1957–60

One new primary fan was installed on the 29th level of No. 5 shaft to replace the two old fans in service in this area.

Forced ventilation was increased to 205,000 c.f.m. This was equivalent to about 750 c.f.m. of air per man on the maximum operating shift.

A total of 81 auxiliary ventilation units was in service at the end of this period.

Other Ventilation Improvements

Since 1935 mine air had been analyzed by the Bureau of Mines or by the company. All records indicated that mine air quality had been satisfactory.

Weekly ventilation meetings attended by supervisory personnel were begun in April 1934. At the time of study, regularly scheduled ventilation meetings were no longer conducted, but shift bosses were responsible for reporting ventilation findings on their daily report forms. The ventilation engineer checked underground conditions almost every day and made a monthly survey of quantities of air at main level intakes and exhausts.

Special ventilation raises were maintained in rock to avoid contamination of air being coursed to working places. These special raises also insured more positive passage of air than forcing air up through caved material. Drifts, too, were driven in rock. A main reason for this was to insure openings for removal of exhaust air. Exhaust air from rock headings was discharged from the face through tubing and up a ventilation pipe in the auxiliary shaft to an abandoned drift and then exhausted through the drift to No. 4 shaft.

History of Dust Control

Wet Drilling

The earliest mention of wet drilling was found in a report dated 1922. At that time, 10 Ingersoll-Rand, No. 448, water-type drills were used in main level development work. A later mention of wet drilling was found in records covering the sinking of the third "lift" of No. 5 shaft. This shaft-sinking job was undertaken during the period from October 1927 to June 1928. Denver (Models 7 and 17), Ingersoll-Rand (N–72), and Sullivan (hand-held) drilling machines were used. Water was piped down the shaft to a manifold from which the water was supplied to the drill machines through ½-inch-diameter hoses. Throughout the 1920's, RB12 auger drills were used in ore.

During 1933 and 1934, company dust counting and ventilation records indicated that tests were being conducted with wet and dry drilling. Most experiments were conducted during drifting and raising, primarily in rock. In February and March of 1934, experiments were conducted with Ruemelin dust traps during dry drilling and resin soap and pine oil emulsions in wet drilling. Neither of these proved very successful. Drilling in ore during this period, as far as could be determined, was still being performed almost exclusively with dry auger drills.

It could not be definitely determined just when 100 percent wet drilling was adopted. Various records indicated that early in 1934 Ingersoll-Rand Water-Leyner drills, types S–70 and N–72, were used for drift and raise work respectively. Drilling in ore was done both wet and dry for at least another year and possibly two. Records from late 1935 and early 1936 were somewhat contradictory, but it was concluded that wet, jackhammer-type, drills were used in hard ore and dry auger drills, which produced relatively little dust, were being used in soft ore. From available records, it can reasonably be assumed that 100 percent wet drilling was in effect by 1937.

Other Use of Water to Control Dust

Various means by which dust may be allayed with water were discussed in nearly all company dust and ventilation records and reports dating back to January 1933. Evidences of earlier uses of water as a dust-control measure, other than wet drilling, were not found. Cross-connections between air and water lines were installed in 1933 and 1934. These connections enabled an air-water mixture (fog) to be blown into a heading after a blast. By the middle of 1934, records revealed that 13 "water blasts" were installed in underground ore places. Water blasts or sprays were installed and used whenever dust-producing operations in a working place contaminated air being coursed to other working places.

At the time of the study, water was used liberally in all rock headings. The back, face, and sides of headings were wet down before drilling and after blasting. Muck piles were wet down before and, as required, during scraping. Shaft stations were wet down when they appeared to be dry and dusty. The underground crusher station was washed down at least two nights a week. Except for wet drilling and water sprays, (water curtains) as required to allay dust in air entering or leaving a heading, the use of water in ore places was avoided as much as possible.

Other Improvements or Dust Control Measures

Establishment of regular blasting times and close control of blasting practices had contributed greatly to reducing the exposure of miners to airborne dust. In 1933 consideration had been given to eliminating all blasting except immediately before the lunch period and at the end of the shift, but the records did not show when this practice first went into effect. Regulated hours for blasting were in effect at the time of the study, except in respect to blasting in rock headings that exhaust air through vent tubing to abandoned drifts, and blasting in hung-up stope holes after barring had failed to cause ore to run.

Although not verified by experimentation and dust counting, company officials felt that scraper loading instead of chute loading of tram cars produced less dust. It was evident that one loading point in each ore block instead of chutes at 25-foot intervals meant fewer dust-producing locations and enabled better dust control on the haulage levels.

Tests were made on various filter-type respirators during the first half of 1934, and within a year respirators were supplied to all men going underground. Orders concerning the use of respirators were circulated and posted. A copy of orders issued about 1935 is shown in figure VI.1. Air-line respirators were also introduced in late 1934 or early 1935. Their use was confined primarily to men working in rock headings. The use of air-line respirators was discontinued in 1942. Approved filter-type respirators were issued to all underground workers at the time of the study.

FIGURE VI.1.—Orders to Captains and Bosses—Use of Respirators Underground. (Prepared in 1935 for Montreal mine.)

Respirators are to be supplied to all men going underground and are to be worn during operations in ore or rock which produce dust and wherever dust is present.

Chief dust-producing operations are—

1. Blasting.
2. Drilling with any type of drill including the auger.
3. Mucking with slusher hoist or shoveling by hand.
4. Running ore or rock from stopes
5. Loading cars from chutes.
6. Loading cars with slusher hoist in loading drifts.
7. Loading skips at skip pockets.
8. Dumping cars at loading pockets.
9. Using blowpipe on cars, motors, drill-holes, etc.
10. Guniting.
11. Sweeping with brooms.

Respirators should be washed by the miners at the end of the shift and kept in clean clothes lockers. Facelets should be changed when they become worn and frayed. Filter pads are to be changed every 4 hours and oftener where necessary as in wet drilling where pads soon become damp and difficult to breathe through.

Dust Prevention Equipment

Water sprays are to be used in rock headings after blasting to wet down broken rock during mucking.

Water blasts in rock headings are to be turned on for a period of 15 to 30 minutes immediately following blasting. The fine mist of the water blast settles dust produced in blasting and prevents it from mixing with fresh air currents. It also helps to kill gases and wets the heading.

Auxiliary fans are to be used in all rock headings with fan tubing up close to the face. Leaks in tubing should be repaired promptly.

Dust prevention and control measures were diligently pursued. Rules and regulations were formulated, circulated, and posted. A copy of Rules for Dust Prevention, prepared in 1936, is shown in figure VI.2.

FIGURE VI.2.—The Montreal Mining Co., Rules for Dust Prevention. (Prepared in 1936.)

Rockwork

Drilling. During all rock drilling in any part of the mine, miners must wear air-line respirators. Others coming into the heading for inspection or other purposes, must wear a respirator.

Mucking. Muck piles must be wetted down during entire mucking period and miners in the heading must wear approved respirators.

Blasting. Blasting is to be done only at the end of the shift unless the smoke and dust pass directly to the main air outlet and nobody is working in the path of the smoke and dust. After blasting, the face and walls of the heading must be washed down with a hose before any work is done.

Ventilation. All rock places must be ventilated with an auxiliary fan set in the fresh air current and provided with metal pipe and Ventube, with end of Ventube kept up to a point not more than 25 feet from the face.

No fan is necessary where the working place is in a main fresh air current.

Orework

Miners are required to wear the ordinary respirators during drilling, slushing, and on entering working places after blasting. After drilling or slushing is finished, miner should continue to wear the respirator for a reasonable length of time.

Blasting should be done at the noon hour or end of the shift wherever the working cycle can be so arranged. Miners must wait in the fresh air current for places to clear after blasting.

Company Dust Counts

Late in 1932 or very early in 1933, specialists from Saranac Laboratories were consulted concerning ventilation problems and dust-control measures. Dust sampling and dust counting by company personnel were begun early in 1933. About 250 samples were collected and recorded during the first year of sampling. Samples were collected in both ore and rock places during drilling, mucking, timbering, and general working operations.

Tables VI.9 and VI.10 show the average company dust counts by operations in ore and rock respectively. Almost 5,500 samples were reviewed, categorized by operation, and averaged to prepare these tables. Only samples representing typical mining operations were included.

Samples collected during the years 1933 to 1949 inclusive were spot check samples of the various operations with, generally, little or no contamination of the atmosphere by mining operations other than the one being sampled. For this reason, the dust concentrations obtained during these years could be interpreted as being somewhat low.

Bureau of Mines personnel conducted a dust study at the Montreal mine during July and August 1936. During this study, 15 duplicate samples were collected. One sample was collected by Bureau personnel and the other by company personnel. These duplicate samples served to check each other's methods. Company and Bureau samplers both used the Greenburg-Smith impinger. The collecting medium

TABLE VI.9.—*Average company dust counts for operations in ore in Montreal mine*

Year	Drilling	Mucking	Timbering	General work	Average all operations
1933	5. 13	4. 82	----------	2. 40	*4. 12
1934	6. 07	9. 76	13. 65	4. 49	*8. 49
1935	1. 79	13. 83	1. 79	3. 01	*5. 10
1936	21. 28	20. 00	5. 19	5. 80	*13. 07
1937	5. 53	1. 95	----------	3. 02	*3. 50
1938	6. 81	13. 36	----------	2. 69	*7. 62
1939	7. 54	6. 09	4. 04	3. 79	*5. 36
1940	14. 07	7. 72	4. 58	2. 14	*7. 13
1941	11. 75	3. 33	----------	5. 11	*6. 73
1942	3. 16	3. 88	3. 37	1. 98	*3. 10
1943	5. 49	5. 38	2. 90	3. 15	*4. 23
1944	4. 42	5. 45	2. 90	3. 32	*4. 02
1945	5. 30	5. 42	2. 50	3. 38	*4. 15
1946	4. 59	5. 84	2. 93	1. 74	*3. 63
1947	5. 55	5. 09	1. 93	2. 44	*3. 75
1948	3. 89	4. 66	1. 71	2. 67	*3. 24
1949	4. 55	5. 10	1. 90	3. 14	*3. 67
1950	3. 70	4. 86	2. 67	2. 60	**3. 45
1951	2. 67	5. 55	1. 61	1. 77	**2. 05
1952	4. 30	6. 89	2. 59	4. 01	**2. 20
1953	3. 67	5. 16	1. 83	3. 01	**2. 48
1954	3. 60	7. 70	1. 80	1. 70	**2. 45
1955	3. 18	8. 57	1. 65	3. 14	**2. 64
1956	2. 12	6. 68	2. 24	1. 78	**2. 24
1957	2. 88	7. 77	3. 15	3. 93	**3. 16
1958	3. 51	7. 26	3. 89	2. 56	**3. 55
1959	3. 14	4. 42	3. 08	1. 61	**2. 27
1960	2. 94	4. 48	2. 72	1. 68	**2. 30

*Algebraic average.
**Weighted average (8-hour exposure).

used by the Bureau was alcohol. Distilled water was used by company samplers. Samples were counted by identical methods. The first seven samples collected and quantitated by company methods were 30 to 70 percent lower than the duplicate Bureau samples. After adopting Bureau recommendations and instructions for sampling and counting, company quantitations were usually within 5 percent of the duplicate Bureau samples. The Greenburg-Smith impinger was used to collect dust samples until June 1939. After that time the midget impinger was used.

Average dust concentrations, as determined by company samples for the past several years, have been within recommended limits. During

TABLE VI.10.—*Average company dust counts for operations in rock in Montrea mine*

Year	Drilling	Mucking	Timbering	General work	Average all operations
1933	17. 27	4. 16	1. 96	1. 31	*6. 18
1934	20. 23	5. 55	1. 68	6. 58	*8. 51
1935	8. 84	9. 08	4. 38	2. 95	*6. 31
1936	15. 05	9. 88	3. 78	3. 36	*8. 02
1937	8. 23	9. 67	12. 00	5. 65	*8. 89
1938	12. 07	9. 94	1. 76	2. 69	*6. 62
1939	5. 54	6. 16	2. 84	1. 64	*4. 04
1940	4. 02	8. 29	2. 76	2. 48	*4. 39
1941	3. 08	5. 68	1. 83	1. 76	*3. 09
1942	5. 85	4. 86	----------	2. 50	*4. 40
1943	6. 50	4. 43	3. 20	2. 72	*4. 21
1944	4. 45	5. 67	2. 62	3. 11	*3. 96
1945	3. 78	2. 74	2. 27	1. 85	*2. 66
1946	6. 13	3. 76	1. 83	1. 96	*2. 64
1947	6. 30	4. 31	1. 87	2. 53	*3. 27
1948	2. 25	2. 94	1. 25	2. 09	*2. 13
1949	4. 09	3. 44	1. 26	1. 87	*2. 67
1950	2. 40	4. 39	1. 77	1. 94	**2. 23
1951	2. 69	3. 60	1. 66	2. 12	**1. 62
1952	3. 04	6. 73	2. 91	3. 01	**1. 88
1953	2. 20	4. 25	1. 93	2. 30	**1. 82
1954	1. 80	3. 64	1. 43	1. 80	**1. 49
1955	3. 30	3. 76	3. 20	2. 53	**2. 22
1956	2. 30	4. 53	1. 56	2. 04	**1. 98
1957	2. 47	3. 51	1. 58	1. 87	**1. 83
1958	4. 11	4. 57	2. 98	2. 90	**2. 68
1959	3. 46	4. 60	2. 77	2. 24	**2. 57
1960	3. 09	4. 66	2. 48	1. 37	**2. 36

*Algebraic average.
**Weighted average (8-hour exposure).

the 5-year period, 1956–60, the average dust concentration for each cycle of operations in rock and ore was as follows:

	Ore	Rock
Drilling	2. 92	3. 09
Mucking	6. 12	4. 37
Timbering	3. 03	2. 27
General work	2. 31	2. 08

Some pertinent practices in dust control, and the dates of their adoption, are summarized:

BEFORE 1933

Wet drilling was used in some main-level development work in 1922 and during shaft sinking in 1927 and 1928.

1933–36

Full time of first ventilation engineer was devoted to ventilation, dust counting, and dust control measures.

Services of Saranac Laboratories were engaged on matters concerning ventilation, dust counting, and medical assistance.

Experiments with wet drilling and use of dust collectors for dry drilling.

Dust respirators were issued to underground miners. Air-line respirators were used by miners on rockwork.

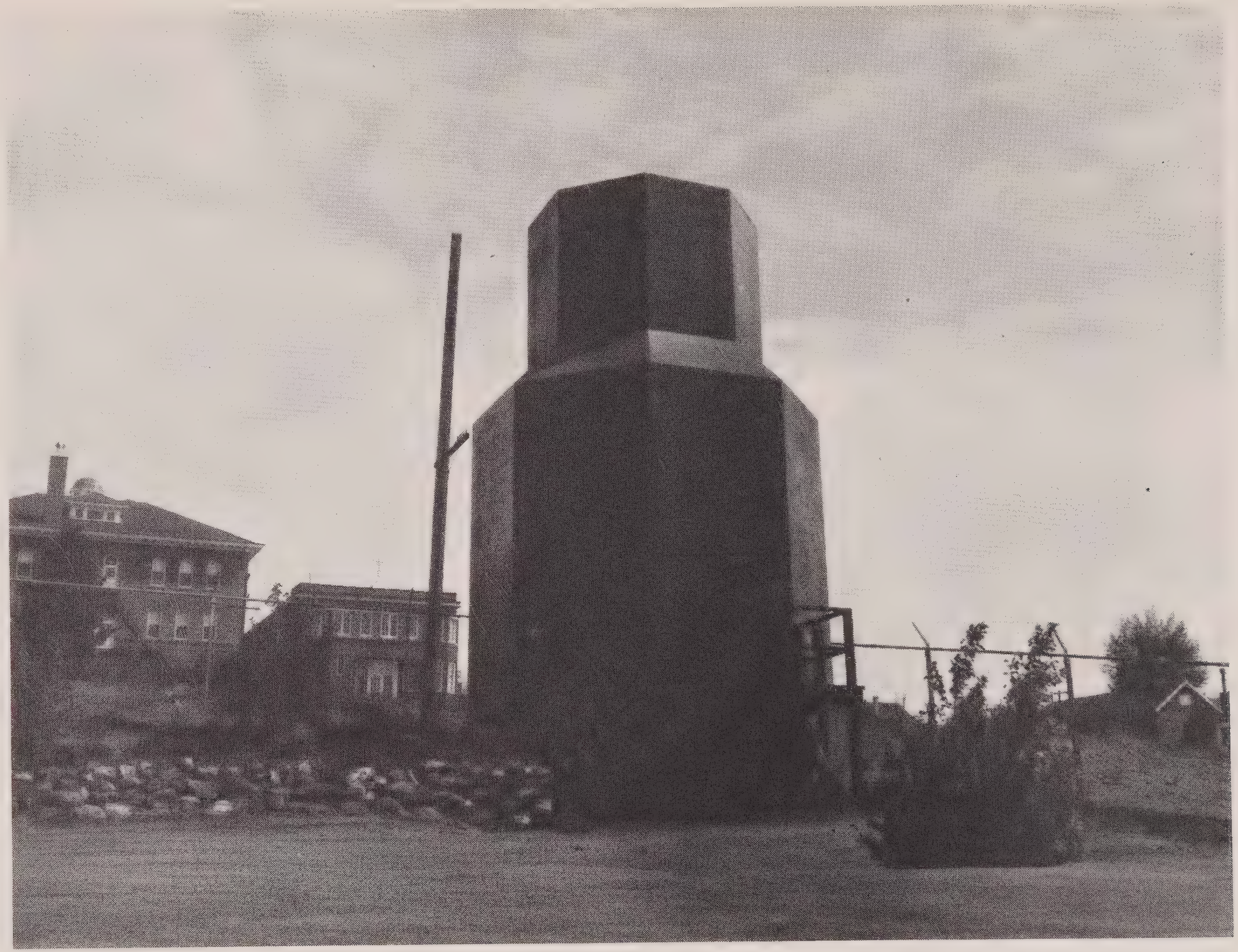
Water sprays and "water blasts" were installed, and water was used extensively for allaying dust.

Regulated hours for blasting were first established.

One hundred percent wet drilling was in effect by the close of this period.

1937–40

Dust respirators were used by miners drilling and mucking ore and mucking rock. Air-line respirators were used by miners during drilling in rock.



Air shaft discharge stack with acoustical lining to reduce noise. (Courtesy of The Anaconda Co., 1963.)

CHAPTER VII

The Use of the New International Radiological Classification of the Pneumoconioses (Geneva—1958) in the Study of Silicosis

THE CLASSIFICATION of the various abnormal lung patterns as seen in roentgenograms of individuals employed in dusty industries has interested many investigators throughout the world over the years. The earlier international classifications of abnormalities in chest roentgenograms of pneumoconioses have been used in other countries much more than in the United States. Fletcher and his colleagues,[1 2*] Gilson and Hugh-Jones,[3] and Van Mechelen and McLaughlin,[4] have been preeminent in their efforts in this area of endeavor and their recorded experiences and suggestions are most helpful and serve as important evaluations of international classifications.

The new international classification of radiological classification of roentgen observations in the pneumoconioses is a good tool and some of the advantages include the following:

1. It classifies the normal and abnormal patterns as seen in the roentgenograms into broad categories—negative, suspect, the several categories of simple and complicated pneumoconiosis—and attempts to define the abnormalities by qualitative and quantitative descriptions that are included within the scope of each category.
2. By the provision of standard reference roentgenograms, visual examples are shown of the various abnormal patterns, which are more effective tools than text definitions and descriptions.
3. By providing standard definitions, terms, and symbols, it lends itself to good statistical evaluation, offers a beginning in overcoming the barriers of language and usage which have impeded international comparisons in the past, facilitates comparisons between industries, and makes comparisons within industries between different time periods more practicable.

Until the time of the 1958–61 revaluation of silicosis in the metal mining industry, the Public Health Service, the States, and other

*Numbers refer to reference list at the end of the chapter.

major research groups in the United States concerned with major studies of the pneumoconioses had not considered seriously the use of international classifications,[5] but had used or modified existing film classifications.

At the beginning of this study of the metal mine workers, however, the Public Health Service had recently participated in the 1958 I.L.O. meeting in Geneva which resulted in a revision of the 1950 I.L.O. radiologic classification.[6] The I.L.O. Geneva classification of 1958 stressed the value of achieving international application of the classification to codify radiologic appearances in a simple reproducible way which would facilitate statistical and epidemiologic investigations to assess the size and nature of pneumoconiotic problems and determine the steps to be taken for the control of the disease and comparisons of studies between industries and industrial countries.

In planning the metal mine study, it was decided to insure expert and unbiased interpretations of the chest roentgenograms by a selected panel of radiologic consultants who would study and interpret the roentgenograms without any knowledge of the miner or of his occupation within the mining industry. The consultants would not represent either the mineowners, the labor unions, or any governmental agency. The three radiologists who were invited and agreed to serve on the panel were:

Benjamin Felson, M.D., professor and director, Department of Radiology, University of Cincinnati College of Medicine, Cincinnati General Hospital, Cincinnati 29, Ohio.

George Jacobson, M.D., professor and head, Department of Radiology, University of Southern California School of Medicine and Chief Radiologist, Los Angeles County Hospital, Los Angeles 33, California.

Eugene P. Pendergrass, M.D., emeritus professor, Department of Radiology, Hospital of the University of Pennsylvania, Philadelphia 4, Pa.

This newly formed panel of radiologists discussed the pros and cons of using the new 1958 I.L.O. classification at its first meeting early in 1959 and decided to attempt its use.* Although the I.L.O. sets of standard reference roentgenograms were not yet available, and did not become available in final form until many months later, an attempt was made to categorize each roentgenogram within the classification according to the written definition and description of each category. After a trial period the panel became satisfied with the classification and used it throughout the study. These consultants

*Subsequently the Pennsylvania Department of Health initiated a survey of central Pennsylvania coal miners in 1959 and also used the I.L.O. 1958 classification in classifying the chest roentgenograms taken during the survey.[7]

read and reported their findings on each film independently to the Public Health Service upon specially prepared rating sheets supplied with each shipment of films. These separate readings and a consensus reading were then entered in the miners' records.

The process of each panel member learning the new classification and applying it uniformly was somewhat difficult especially during the early months of the study. Wall charts were prepared for easy reference to the schematic presentation of the classification and to the basic definitions shown in figure VII.1. Discussions were held at each regular quarterly panel meeting to crystallize the panel's thinking on classifying the roentgenograms which presented problems, especially in the "gray areas" between categories.

As the study continued, the panel members gained valuable experience in studying and interpreting a large number of roentgenograms. As a result of discussion and comparison of variations in interpretation at quarterly meetings, it was noted that a decreasing number of roentgenograms needed reconsideration. There were numerous problems, however, that arose from time to time that required special attention.

With the large volume of roentgenograms being processed, it was not feasible to attempt to review all films at the quarterly meetings to reconcile disagreements in interpretation among the three members of the panel. Then, too, it was found that there was sometimes a lack of unanimity even after such a review and discussion. Under such circumstances, the "consensus interpretation" (reading) was developed on a majority rule basis, with certain exceptions. Examples of such include the following:

1. If two panelists selected the category "1m" and one selected "2n"; the consensus was "1m."
2. If there were two who recorded "A," and one a "B," the consensus was entered as "A."
3. If there were two "Z" interpretations and the third was "O" or "2p," the consensus was "Z."
4. An exception to a majority obtained when there were two "O" interpretations and one positive reading. The recording was "Z" which is a doubtful category based on a positive interpretation by one radiologist.

In all of the readings of the "A," "B," or "C" categories of conglomerate and massive lesions which indicate complicated silicosis, an effort was made also to categorize the background of small opacities. The majority rule held for qualitative and quantitative evaluation of the small opacities and the large lesions. Thus a "B2m," "C2n," and a "B3n" interpretation would be rated as a "B2n" consensus. It was possible to obtain a background reading on almost every roentgenogram on which the large opacities could be classified.

FIGURE VII.1.—I.L.O. radiological classification of chest films for Public Health Service metal mines survey

<table>
<tr><td rowspan="2">Type of opacities.</td><td colspan="2" rowspan="2">Film quality</td><td rowspan="2">No pneumoconiosis</td><td rowspan="2">Doubtful</td><td colspan="13">Pneumoconiosis</td></tr>
<tr><td colspan="9">Small opacities</td><td colspan="4">Large opacities</td></tr>
<tr><td>Quantitative features.</td><td rowspan="2">Unsatisfactory film.</td><td rowspan="2">Poor film.</td><td rowspan="2">O</td><td rowspan="2">Z</td><td colspan="3">1</td><td colspan="3">2</td><td colspan="3">3</td><td rowspan="2">AX</td><td rowspan="2">A</td><td rowspan="2">B</td><td rowspan="2">C</td></tr>
<tr><td>Qualitative features.</td><td>p</td><td>m</td><td>n</td><td>p</td><td>m</td><td>n</td><td>p</td><td>m</td><td>n</td></tr>
</table>

<table>
<tr><td>Additional symbols.</td><td>co</td><td>cp</td><td>cv</td><td>di</td><td>em</td><td>hi</td><td>pl</td><td>px</td><td>tb</td><td>ca</td><td>cn</td><td>es</td><td>nt</td><td>ns</td></tr>
<tr><td>Film quality.</td><td colspan="14">Unsatisfactory film—impossible to read.
Poor film—film of such quality as to make detailed classification difficult.</td></tr>
<tr><td>No pneumoconiosis.</td><td colspan="14">O—No radiographic evidence of pneumoconiosis.</td></tr>
<tr><td>Doubtful opacities.</td><td colspan="14">Z—Increased lung markings. Uncertain as to diagnosis of silicosis.</td></tr>
</table>

	Pneumoconiosis	
Small opacities.	The categorization depends on the extent and the profusion of the opacities: 1. A small number of opacities in an area *equivalent to at least two anterior rib spaces* and at the most not *greater than one-third of the two lung fields.* 2. Opacities more *numerous and diffuse than in category 1 and distributed over most of the lung fields.* 3. Very numerous profuse *opacities covering the whole or nearly the whole of the lung fields.*	The following types are defined according to the greatest diameter of the predominant opacities: p—Punctiform opacities. *Sizes up to 1.5 mm.* m—Micronodular or miliary opacities. Greatest diameter *between 1.5 mm. and 3 mm.* n—Nodular opacities. *Size between 3 and 10 mm.*
Large* opacities.	AX—Suspicion of large opacities or coalesence. A—An opacity having a longest diameter of between 1 and 5 cm. or several opacites each *greater than 1 cm,* the sum of whose longest *diameters does not exceed 5 cm.* B—One or more opacities, *larger or more numerous than those in category A,* whose combined area *does not exceed ⅓ of 1 lung field.* C—One or more large opacities whose combined area exceeds ⅓ of 1 lung field.	

Additional symbols

co—Abnormal cardiac outline.
cp—Cor pulmonale.
cv—Cavity.
di—Significant distortion.
em—Marked emphysema.
hi—Abnormal hilar shadows.
pl—Pleural abnormalities.

px—Pneumothorax.
tb—Tuberculosis suspect.
ca—Cancer suspect.
cn—Calcified nodules in small opacities.
es—Eggshell calcification.
nt—Nontuberculous infection.
ns—Probably not silicosis.

*The background of small opacities should be specified as far as possible.

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The question of the "L" category indicating numerous linear or reticular opacities within the pneumoconiosis classification was a problem from the beginning of the study. The "L" designation appeared infrequently on the panel's interpretation and, when it did, there was lack of agreement. Accordingly, after using the "L" category for many months, the panel agreed to omit this category from the classification sheets. This did not affect the use of the "Z" category for roentgenograms considered to be "suspect" or "doubtful" because of the presence of abnormal lung markings or questionable nodules suggestive of silicosis.

There are a group of shadows that are seen in the lower lung fields near the costophrenic sulci and the lateral chest wall in some of the metal mine workers. The lines have been considered by Kerley [8] and others and are commonly referred to as Kerley's "A," "B," and "C" lines. Some of the panel members believe that these lines when present represent abnormal changes and one member believes that he has recorded such changes in healthy chests without cardiac lesions and without harmful dust exposure.

It is not thought that the I.L.O. classification (1958) is a finished product; in fact, an important conference was held in April 1962 with some of the pneumoconiosis investigators in the United Kingdom which provided additional suggested modifications of the classification that may lead to a better understanding and stimulation of its use by others.

The need for additional symbols beyond the nine listed in the I.L.O. classification to show other significant abnormalities of the chest was apparent soon after the study was begun. The last five symbols in the list recorded below were added to the checklist of additional symbols.

co—abnormal cardiac outline.
cp—cor pulmonale.
cv—cavity.
di—significant distortion.
em—marked emphysema.
hi—abnormal hilar shadows.
pl—pleural abnormalities.
px—pneumothorax.
tb—tuberculosis suspect.
ca—cancer suspect.
cn—calcified nodules in small opacities.
es—eggshell calcification.
nt—nontuberculous infection.
ns—probably not silicosis.

Old tuberculous scars and other lesions were described separately as seemed desirable under "Remarks", and any likely significance noted. Ghon-like calcifications were not routinely recorded.

During the course of the panel meetings, it was noted that rather frequently well-defined eggshell calcifications occurred in the hilar nodes in association with the characteristic lung field pattern of silicosis. After several discussions, which drew upon the evidence obtained in the study and upon the earlier experience of the panel, it

was agreed to try to determine whether eggshell calcifications are a diagnostic sign of silicosis, even sometimes in the absence of other characteristic lung field markings.

Accordingly, all roentgenograms previously interpreted showing any suggestion of eggshell calcifications were reviewed again independently and again in discussion at the panel meetings.

After considerable discussion it was agreed that shadows suggestive of eggshell calcification must meet certain well-defined criteria to be considered as a diagnostic sign of silicosis. These criteria are:

1. The presence of shell-like calcifications measuring up to 2 mm. in thickness in the peripheral zone of at least two lymph nodes.
2. These calcifications may be solid or broken.
3. In at least one of the lymph nodes the ringlike shadow must be complete.
4. The central portion of the lymph nodes may show, in addition, speckled calcification.
5. The affected lymph node must be at least 1 cm. in its greatest diameter.

Since the adoption of these criteria, 47 roentgenograms were classified as showing well defined eggshell calcifications. Of these 47 roentgenograms, the lung field markings of 31 also were classified as showing simple or complicated silicosis, 10 with Z or doubtful markings, and 6 with an O or negative interpretation for the lung fields themselves.

Another problem that arose was that involved when a classification was made of a category (3m for example), indicating simple silicosis, but one or two of the readers thought there was a conglomerate shadow which was suspect or positive for a large opacity. Accordingly it was agreed to provide an additional category "AX" signifying suspicion of a large opacity or coalescence in addition to the specified category indicating simple silicosis. Thus a consensus reading of 3mAX still denoted simple silicosis but indicated that either two readers thought it was also suspicious of complicated silicosis or that only one reader thought it showed evidence of the A category in addition to the 3m reading. Therefore, this coding of AX merely indicated that the roentgenogram in the simple silicosis category is also suspect in regard to complicated silicosis. It is believed that this is an important addition to the classification in suggesting a possible transition stage from simple to complicated pneumoconiosis.

Variations in readings between the qualitative readings p, m, and n were observed rather frequently, especially between m and n. Similarly there were variations in the quantitative readings of categories 1, 2, and 3, especially between categories 2 and 3. Generally, however, two of the three panelists would agree on m versus n, and category 2

versus 3, so it was usually rather easy to arrive at a consensus for these categories. An exception would be when other problems were involved such as the third reader considering the roentgenographic findings outside of the grouping of simple silicosis.

During the course of the quarterly meetings, the question arose on several occasions as to whether there was sufficient difference between categories 2 and 3 to justify what was often a difficult decision. The same question arose as to the distinction between the "m" and "n" sized nodules, which was frequently a problem. In both instances, it was agreed to continue using these categories.

Another problem that came up for consideration late in the second year of the study was the retention of category 1. It was noted that this category had been utilized rather infrequently and there was often a problem as to whether the shadow pattern might rather be classified as category 2, or sometimes even Z or doubtful. At the same time, there was the possibility that as the panel had gained experience with the classification there may have been a change in practice in classifying such films in this category. The question of possible changes in reading practice also came up with regard to the Z or doubtful classification. It was thought that the standards for reading this category might have changed over the 2-year period films were being read.

Accordingly, it was agreed to reread independently all the category 1, and the category Z films read up to that time, i.e., through the first 40 mines surveyed during the study. The rereading of the category 1 roentgenograms satisfied the panel that the category should be retained as a useful one in the classification to show early silicosis. The rereading of the roentgenograms classified as Z or suspect showed that the panelists had been drawing closer together on their interpretations and that a sizable proportion of roentgenograms with a previous consensus of Z had now reverted to the O or negative classification. The net result of these rereadings of both Z and category 1 films was to change a subtsantial number of roentgenograms from Z or "suspect" to the O or negative category.

The analysis of chest films classified as negative or suspect with regard to silicosis, simple silicosis and complicated silicosis has been discussed in detail in chapter V, and the relationship of silicosis to the many variables in the metal mining industry has been shown. The relationship of the several categories of silicosis to dyspnoea or breathlessness was also described.

Table VII.1 shows the I.L.O. categorical classification of all 476 chest films considered to be consistent with a diagnosis of silicosis in the study group of 14,076 metal mine employees. It will be noted that in the 305 chest films showing simple silicosis, the great preponderance of films, 213 in all, were classified as category 2, which seems to be typical of simple silicosis. Of these 213 category 2 films, a

large majority, 163 cases, were classified as category m, meaning small opacities usually from 1.5 mm. to 3 mm. in diameter. Thus, the classification of 2m accounted for over one-half of the films showing evidence of simple silicosis.

TABLE VII.1.—*I.L.O. radiological classification of silicotic chest films in study group of 14,076 metal mine workers*

Grand total	Small opacities—simple silicosis											
	Category 1				Category 2				Category 3			
476	Total	p	m	n	Total	p	m	n	Total	p	m	n
305*	49	2	42	5	213	33	163	17	29	8	17	4
	Large opacities—complicated silicosis											
	Category A				Category B				Category C			
	Total	1	2	3	Total	1	2	3	Total	1	2	3
171	†104	16	62	19	**44	0	32	11	‡23	0	11	11
	Total	p	m	n	Total	p	m	n	Total	p	m	n
171	†104	4	72	21	**44	0	31	12	‡23	1	15	6

*Includes 14 films eggshell only, without other classification.
†Includes 6 films ZA, 1 film A only.
**Includes 1 film ZB.
‡Includes 1 film C only.

Of the 171 chest films considered to indicate complicated silicosis, by far the largest number, 104, were considered to be in the least advanced grade, category A—meaning a large opacity (ies), ranging from 1 cm. up to 5 cm. in the greatest diameter. Category B, indicating more advanced complicated silicosis, accounted for 44 cases, while the most advanced group, category C, contained only 23 cases or about 5 percent of all silicotic films. It was noted throughout this study that there were few of the far advanced silicotic films frequently observed in the early studies of the Public Health Service.

In considering the background of small opacities of the 171 films included in the A, B, and C categories, the categories 2 and m again dominated the picture with 105 films classified as belonging in category 2, and 118 films showing category m opacities. A difference was noted in the most advanced category C, however, where about half of these films were also classified with a category 3 background and two-thirds also were classified as category m.

Table VII.2 shows the broad I.L.O. radiological classification of the 12,487 chest films from the 50 metal mines where length of exposure has been shown previously in chapter V. It will be noted that in the 3 broad years-of-exposure groups, the percent of normal or nonsilicotic films decreases from 97.6 percent to 82.6 percent. It will be noted that after 25 years of mining the rates of doubtful and silicotic categories increases rather sharply in those categories with sufficient numbers to make a valid comparison.

TABLE VII.2.—*I.L.O. categorization of lung field markings by years of work at 50 metal mines**

Lung field markings	Total		Years at metal mines					
			0–25		25–34		35+	
	Workers examined							
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Total	12, 487	100. 0	10, 744	100. 0	1, 221	100. 0	522	100. 0
Nonsilicotic	11, 928	95. 5	10, 482	97. 6	1, 015	83. 1	431	82. 6
Doubtful	133	1. 1	81	. 7	36	2. 9	16	3. 1
Category 1	43	. 4	21	. 2	19	1. 6	3	. 6
Category 2	186	1. 5	92	. 9	68	5. 6	26	5. 0
Category 3	29	. 2	14	. 1	9	. 7	6	1. 1
Eggshell	14	. 1	4	. 0	6	. 5	4	. 7
Category A	97	. 8	37	. 3	40	3. 3	20	3. 8
Category B	39	. 3	7	. 1	18	1. 5	14	2. 7
Category C	18	. 1	6	. 1	10	. 8	2	. 4

*Excludes uranium mine workers.

Table VII.3 shows additional categorical listing of all 14,858 chest films taken in the X-ray survey including the 14,076 films included in the study group, and, in addition, the films which were not included for reasons discussed previously; such as more than 5 years of exposure in other dusty trades.

Among the 337 films classified as simple silicosis, over two-thirds of the films were classified as 2m (182), 1m (46), or 2p (36), with relatively few in the remaining categories of simple silicosis. Sixteen of the thirty-one eggshell cases not otherwise classified appear in this grouping. Of the 337 cases classified as simple silicosis, 138 films were also designated AX, meaning a suspicion of coalescence or large opacities.

Of the 185 films classified as complicated silicosis, the largest numbers in the detailed analysis fell within the categories A–2m (47), B–2m (25), A–1m (16), A–2n (15), A–3m (12), and C–2m (10), but there was a wide scatter throughout the other categories.

TABLE VII.3.—*I.L.O. detailed classification of all 14,858 chest roentgenograms taken in metal mines study, including 671 employees with exposure in other dusty trades*

	Number	Percent
Total workers	14, 858	100
Nonsilicotics	14, 166	95. 4
Doubtful or suspect	170	1. 1
Simple silicosis	*337	2. 3
Category:		
1p	2	0
1m	46	. 3
1n	5	0
2p	36	. 3
2m	182	1. 3
2n	17	. 1
3p	9	. 1
3m	19	. 1
3n	5	0
ES	16	. 1
Complicated silicosis	185	1. 2
Category:		
A–1m	16	. 1
A–2p	5	0
A–2m	47	. 3
A–2n	15	. 1
A–3p	1	0
A–3m	12	. 1
A–3n	8	. 1
A–Z	7	0
A only	1	0
B–1m	1	0
B–2m	25	. 2
B–2n	8	. 1
B–3m	7	0
B–3n	5	0
B–Z	1	0
C–2m	10	. 1
C–2n	3	0
C–3p	1	0
C–3m	8	. 1
C–3n	3	0
C only	1	0

*Simple silicosis includes 138 cases in AX classification.

From the experience gained in this study of silicosis, the problem of classifying chest roentgenograms by three experienced interpreters is relatively simple within the broad I.L.O. groupings of small opacities, consistent with simple silicosis, and large opacities, consistent with complicated silicosis. There were somewhat greater problems involved in classifying roentgenograms in the gray zones between early silicotic changes, the doubtful or suspect groups, and a negative reading. Not infrequently there were one negative and two positive readings; one negative and two suspect readings; one positive, one suspect and one negative reading; or any combination of these early or borderline changes so important in evaluating pneumoconiosis control programs. While the experience gained by reading and discussing a great volume of roentgenograms during this study reduced this problem very considerably, there is sometimes a real difference of opinion as to whether a given roentgenogram is within normal limits, or within the suspect or early silicotic categories. Apparently this situation occurs with any kind of classification. It is believed that the consensus rating of "Z" or doubtful is an important one to help with this problem. Serial film studies and special radiological techniques will reconcile many of the problem cases.

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APPENDIX

Effects of Silicosis and Other Factors on Pulmonary Function

INTRODUCTION

THE TWO METHODS for making certain tests of pulmonary ventilatory function by a series of single maximal exhalations were described in chapter V, page 107. These tests were made with the Collins 6 liter recording vitalometer and the Wright peakflow meter. These instruments were selected as being suitable for use under the many conditions of testing encountered during the field study of silicosis in the metal mining industry.

Four measurements were made of pulmonary ventilation function: (1) Peak expiratory flow (PEF) measured in liters per minute; (2) forced expiratory 1-second volume (FEV_1) measured in liters; (3) forced vital capacity (FVC) measured in liters; and (4) forced expiratory 1-second volume divided by forced vital capacity (FEV_1/FVC) measured in percent. This section of the report deals primarily with the effects of silicosis on these pulmonary function test results. In addition, some estimates of the effects of other factors have been made. Factors believed to be relevant to pulmonary function testing, other than silicosis, and which can be accounted for in this analysis include:

1. Height.
2. Age.
3. Smoking history.
4. Number of years in underground mining.
5. Total years in mining.

As shown previously, X-ray evidence of silicosis was not found in men under 35 years of age; consequently they have been excluded from this presentation. For men 35 years of age and over, complete information was available for chest X-ray findings, all 4 measures of pulmonary function, and all of the 5 other variables noted above on a total of 7,817 actively employed metal mine workers. The following analyses have been confined to these 7,817 men (there were no females in the study group).

EFFECTS OF SILICOSIS ON PULMONARY FUNCTION

The effects of silicosis on pulmonary function were estimated by developing predicted test results on the basis of men without silicosis and comparing these with test results actually observed in men with silicosis. The 7,817 men included in this analysis have been classified on the basis of X-ray chest findings as follows:

	No. of Cases
Group 1: Those whose chest film was coded 0, meaning no X-ray evidence of silicosis or other pneumoconiosis, or 1, meaning suspected or doubtful pneumoconiosis	7, 404
Group 2: Those whose chest X-ray film was coded 2, meaning changes consistent with simple silicosis	267
Group 3: Those whose chest X-ray film was coded 3, meaning changes consistent with complicated silicosis	146

These three groups are referred to in this report as the groups with no silicosis, simple silicosis, and complicated silicosis. Only 1.7 percent of the films in group 1 were coded 1; the rest were coded 0.

Table A.1 shows the average values for each of the four measures of pulmonary ventilatory function tests for men with no silicosis, simple silicosis, and complicated silicosis. For every one of the four measurements of pulmonary function, the average value is less for those with silicosis than for those with no silicosis. Also, for every one of the four measurements, the average value is less for those with complicated silicosis than for those with simple silicosis.

TABLE A.1.—*Average values for four measurements of pulmonary function of metal mine workers 35 years of age and over with and without silicosis*

Metal mine workers with—	Number of workers	Measurement of pulmonary function			
		PEF	FEV_1	FVC	FEV_1/FVC
No silicosis	7, 404	483	2. 96	4. 22	70. 1
Simple silicosis	267	441	2. 61	3. 95	66. 3
Complicated silicosis	146	382	2. 41	3. 68	63. 1

The comparisons in table A.1 are complicated by the fact that the metal mine workers with silicosis tend to be older and to have worked more years in mining than those with no silicosis and, as noted above, these factors no doubt have some effect on pulmonary function. The decline observed in table A.1 cannot, therefore, be entirely attributed to silicosis. Table A.2 shows that the average metal mine worker with complicated silicosis was 8 years older and worked in underground mining 10 years longer than the average metal mine worker with no silicosis. He has also spent more total years in mining and

he had a lower average code for smoking. The complete code for smoking which is used in this report is shown in table A.3; former smokers are given a relatively low value in the code. The lower average smoking codes for workers with silicosis reflects the higher proportion of men among the silicotic groups than among the nonsilicotic group who reported having discontinued smoking.

TABLE A.2.—*Average values for 5 factors of metal mine workers 35 years and over with and without silicosis*

Metal mine workers with—	Number of workers	Height (inches)	Age (years)	Smoking (code from 0 to 60)	Years in underground mining	Total years in mining
No silicosis	7, 404	68. 9	46. 2	32. 4	11. 4	16. 5
Simple silicosis	267	68. 5	52. 6	30. 3	19. 7	24. 9
Complicated silicosis	146	68. 7	54. 6	28. 3	21. 7	28. 6

TABLE A.3.—*Classification of the cigarette smoking history among metal mine workers*

Code	Definition
0	Never smoked cigarettes.
10	Former cigarette smoker (ceased smoking more than 1 year ago).
20	Smoked for less than 10 years and now smokes less than ½ pack per day.
30	Smoked for 10–24 years and now smokes less than ½ pack per day, or, smoked for less than 10 years and now smokes ½–1 pack per day.
40	Smoked for 25 or more years and now smokes less than ½ pack per day, or smoked for 10–24 years and now smokes ½–1 pack per day, or smoked for less than 10 years and now smokes over 1 pack per day.
50	Smoked for 25 or more years and now smokes ½–1 pack per day, or smoked for 10–24 years and now smokes over 1 pack per day.
60	Smoked for 25 years or more and now smokes over 1 pack per day.

Table A.4 compares the pulmonary function test results observed among men with silicosis with test results which would be predicted from an analysis of the 7,404 active metal mine workers without silicosis. Predicted values were obtained in the following manner: The 7,404 metal mine workers with chest films that were negative for silicosis were used to establish a mathematical formula showing the simultaneous relation between pulmonary function and all five of the factors shown in table A.2, using a multiple regression technique. The resulting formulas are presented in table A.5. Only those coefficients that are statistically significant at the 1-percent level are shown in table A.5, which is discussed subsequently.

TABLE A.4.—*Comparison of observed values of pulmonary functions for metal mine workers 35 years of age and over who have silicosis with values predicted from metal mine workers without silicosis*

Metal mine workers with—	Measurement of pulmonary function			
	PEF	FEV_1	FVC	FEV_1/FVC
Simple silicosis:				
Predicted	457	2. 72	3. 94	68. 0
Observed	441	2. 61	3. 95	66. 3
Percent reduction	4	4	0	3
Complicated silicosis:				
Predicted	453	2. 67	3. 89	67. 4
Observed	382	2. 41	3. 68	63. 1
Percent reduction	16	10	5	6

Using the formulas in table A.5, the predicted value of pulmonary function can be computed using average values for the characteristics of height, age, smoking, years in underground mining, and total years in mining. These formulas were used to compute the predicted value of pulmonary function for groups with no silicosis but having the same average values for these characteristics as the metal mine workers with simple silicosis and with complicated silicosis. This was done by substituting in the formulas the average values for the characteristics of these groups as shown in table A.2.

TABLE A.5.—*Formulas relating 4 measurements of pulmonary function to height, age, smoking, underground mining employment, and total mining employment for 7,404 metal mine workers 35 years of age and over with no silicosis*

Formulas

$$PEF = 271.8 + 5.95X_1 - 3.83X_2 - 0.74X_3 - 0.77X_4 + 0.67X_5$$

$$FEV_1 = -0.432 + 0.0755X_1 - 0.0344X_2 - 0.0053X_3 - 0.0026X_4$$

$$FVC = -3.90 + 0.139X_1 - 0.029X_2 - 0.002X_3 - 0.004X_5$$

$$FEV_1/FVC = 123.86 - 0.499X_1 - 0.355X_2 - 0.092X_3 - 0.071X_4 + 0.049X_5$$

Symbols:

X_1=Height (inches).
X_2=Age (years).
X_3=Amount of smoking (see table A.3).
X_4=Number of years in underground metal mining.
X_5=Total number of years in metal mining.

To illustrate how these results were obtained, the computations are shown for obtaining the predicted value for PEF in a group having the average characteristics of metal mine workers with complicated silicosis, which is shown in table A.4 to be 453 liters/minute. Substitution of the values in Table A.2 for height, age, smoking, years in underground mining, and total years in mining into the formula for PEF yields:

$$
\begin{aligned}
\text{PEF} &= 271.8+5.95\times 68.7-3.83\times 54.6-0.74\times 28.3-0.77\times 21.7 \\
&\qquad +0.67\times 28.6 \\
&= 271.8+408.765-209.118-20.942-16.709+19.162 \\
&= 271.8+181.158 \\
&= 453 \text{ liters/minute}
\end{aligned}
$$

These computations yield a predicted value of 453 liters per minute for nonsilicotic metal mine workers having the same average characteristics as those with complicated silicosis; this can be compared with the average value of 382 liters per minute actually observed for the group with complicated silicosis as shown in table A.1. The percent reduction of the observed value from the predicted value is 16 percent.

It must be borne in mind that there is a large amount of variation from one metal mine worker to another in the measurements of pulmonary function. Five of the factors that might produce this variability have been taken into account in computing the reduction of 16 percent in PEF for metal mine workers with complicated silicosis. There are undoubtedly other factors affecting pulmonary function that have not been taken into account. If it is assumed that the frequency of these other factors is no different among metal mine workers with complicated silicosis than it is in those with no silicosis, then the reduction of 16 percent can be attributed to complicated silicosis.

In table A.4, all the reductions in pulmonary function are statistically significant at the 1 percent level, with the exception of FVC and FEV_1/FVC for metal mine workers with simple silicosis.

The formulas presented in table A.5 yield only approximations since in order to simplify the computations an assumption was made that the relationship of the independent variables (i.e., age, height, etc.) to pulmonary function test results was linear and additive. In general, this assumption is probably valid and the formulas presented in table A.5 are useful in describing the contributions of each of the five variables studied to pulmonary function test results when average values near the mean values shown in table A.2 are used. The results may become less reliable as the characteristic values substituted in the formulas depart farther from the means shown in table A.2.

EFFECTS OF OTHER FACTORS ON PULMONARY FUNCTION

Table A.6 presents estimates of the separate effects of aging, smoking, and underground mining on pulmonary function test results. In compiling these data average values for miners without silicosis were assumed. For example, data for aging compares pulmonary function for a group of men without silicosis of average height, smoking, and work history (see table A.2), who are 35 years of age with a group otherwise comparable but who are 55 years of age. Similar comparisons are made for men who do not smoke (smoking code 0) and heavy smokers (smoking code 60); and for men without a history of underground mining and men with 20 years of underground mining.

TABLE A.6.—*Average decline in 4 measurements of pulmonary function associated with 20 years of aging, smoking, and 20 years of underground mining, among metal mine workers 35 years of age and over without silicosis*

Predicted value of pulmonary function	Measurement of pulmonary function			
	PEF	FEV_1	FVC	FEV_1/FVC
Aging:				
For age 35	526	3. 36	4. 53	74. 1
For age 55	449	2. 68	3. 95	67. 0
Percent reduction	16	23	14	10
Smoking:				
No smoking	507	3. 15	4. 27	73. 1
Heavy smoking	463	2. 83	4. 15	67. 6
Percent reduction	9	10	3	8
Underground mining:				
No underground mining	492	3. 01	4. 21	70. 9
20 years underground mining	476	2. 96	4. 21	69. 5
Percent reduction	3	2	0	2

It is apparent that of these three variables the effects of aging are by a considerable margin the most important. Underground mining, by the method of calculation used, had only a small effect on pulmonary function measurements when other relevant factors were held constant in this large group of metal mine workers with no X-ray evidence of silicosis.

It is of interest to compare the effects of silicosis on pulmonary function (shown in table A.4) with the effects of other variables (shown in table A.6) even though the data in tables A.4 and A.6 were derived somewhat differently. Generally it may be stated that complicated silicosis probably has almost as much effect on pulmonary function as 20 years of aging and that cigarette smoking is of considerable importance even when compared with silicosis.

CORRELATION BETWEEN FOUR MEASUREMENTS OF PULMONARY FUNCTION

To answer the question of how the four measurements of pulmonary function are related to each other, the correlation coefficient of each of the tests with each of the other tests was computed. This was done separately for each of the three groups of metal mine workers, i.e., those with no silicosis, those with simple silicosis, and those with complicated silicosis. The results are presented in table A.7.

TABLE A.7.—*Correlation coefficients among 4 measurements of pulmonary function for metal mine workers 35 years of age and over*

Comparison of pulmonary function measurements	Correlation coefficient for workers with—		
	No silicosis	Simple silicosis	Complicated silicosis
FEV_1 with FVC	0.74	0.70	0.67
FEV_1 with PEF	.68	.75	.72
FEV_1 with FEV_1/FVC	.63	.64	.60
FVC with PEF	.46	.46	.69
FVC with FEV_1/FVC	.03	.09	.26
PEF with FEV_1/FVC	.52	.57	.70

All the correlation coefficients shown in table A.7 are statistically significant at the 1-percent level, with the exception of the correlation between FVC and FEV_1/FVC in the 7,404 metal mine workers with no silicosis and the correlation between FVC and FEV_1/FVC in the 267 metal mine workers with simple silicosis. These two correlations could easily have occurred by chance.

Among the metal mine workers with no silicosis, the FEV_1 is highly correlated with FVC. When FEV_1 is divided by FVC, the ratio FEV_1/FVC is no longer correlated highly with forced vital capacity. As would be expected, PEF is correlated more highly with FEV_1 than with either of the other two measurements of pulmonary function.

For the group of metal mine workers with simple silicosis the correlation coefficients are about the same as for the group of nonsilicotics. For the group of metal mine workers with complicated silicosis there are two departures from the correlation coefficients observed in the group with no silicosis and in the group with simple silicosis. The first departure is that FEV_1/FVC retains some degree of correlation with FVC even though the ratio contains FVC as the denominator. This probably reflects the fact that the denominator FVC is itself reduced on the average because these men have complicated

silicosis but that FEV_1 is reduced to an even greater degree with advancing disease. The second departure is that the correlation coefficient of PEF with FVC and with FEV_1/FVC has increased considerably. This probably reflects the fact that when the silicosis is advanced, all the measurements of pulmonary function show reduced values and, therefore, correlate highly with each other.

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